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# Armed Services Technical Information Agency

# AD

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9th Part of No. AAEE/843/1.



MINISTRY OF SUPPLY

**AEROPLANE AND ARMAMENT  
EXPERIMENTAL ESTABLISHMENT**

BOSCOMBE DOWN

HASTINGS C. MK. 2 WD. 476  
(HERCULES 106)

ENGINE COOLING TESTS AT 80,000 LB. WITH AND WITHOUT  
COOLING FANS, AND EXTERNAL STORES

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9th Part of Report No. AAEE/843/1.

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT  
BOSCOMBE DOWN

-7.10.1953

Hastings C. Mk. 2. WD. 476  
(Hercules 106)

Engine cooling tests at 80,000 lb. with and without  
cooling fans, and external stores

A. & A.E.E. Ref.: AAEE/5707,j/10.  
Period of Tests : June, 1953.

Progress of issue of Report

Report No.	Title	
4th Part of AAEE/843/1.	WD.475	Brief handling trials.
5th - do -	WD.475	Compass assessment.
6th - do -	WD.476	Take-off performance.
7th - do -	WD.476	Noise level measurements.
8th - do -	WD.476	Investigation of air speeds during take-off and climb away.

Summary

The results of the engine cooling tests on WD.476, after making allowance for such factors as the lower performance obtained with an external load of higher drag than that carried on test and for a less severe engine-operating condition on the climb, indicate that the cylinder temperature limitations will be exceeded as follows with the cooling fans removed and under tropical summer standard conditions:-

- |       |  |       |
|-------|--|-------|
| (i)   | Take-off   | 10°C. |
| (ii)  | Climb  | 15°C. |
| (iii) | Level flight at 8,000 feet   | 15°C. |
| (iv)  | Level flight at 1,000 feet, at a dropping speed of 115 knots, I.A.S. | 30°C. |

With the cooling fans fitted, (iv) is the only case likely to give rise to the limitations being materially exceeded.

On the assumption that the conditions of manoeuvre and power settings relevant to the above, are representative of those used by Transport Command in their operation of Hastings aircraft carrying external stores, without cooling fans, then it is reasonable to expect that similar levels of cylinder temperature are realised in Service. In fact, they may be materially higher, by reason of, - (a) the indications of cylinder temperatures displayed by the standard pyrometers to the aircrew being much lower than those measured on the same cylinder by test pyrometers, and (b) by the location of the standard pyrometers on cylinder No. 14 which is not the hottest in all instances, resulting possibly in the cowl gills being used in the shut position, when, in fact, they should be open for increased cooling.

The foregoing does not take into account such circumstances as asymmetric powered flight following an engine failure on take-off and the practising of overshoots with simulated engine failure. Either of these would tend to result in a material increase in cylinder temperature at take-off power setting.

/Since it....

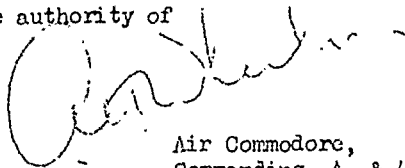
Since it appears that there has been no undue increase in the rate of engine or relevant component failure during Transport Command's operation of Hastings aircraft in tropical climates with cooling fans removed, it is suggested that the current cylinder temperature limitations for the Hercules 106 can be materially exceeded with safety.

The potential dangers arising from the mal-functioning of the standard single point pyrometers, combined with the fact that the cylinder on which it is located is not always the hottest, warrant consideration being given to the deletion of the equipment in its present form.

The frequency with which mechanical failures of the cooling fan installation has occurred on Hastings aircraft operated by Transport Command, suggests that their retention may introduce a hazard greater than that due to the increase of cylinder temperature arising from their removal.

An investigation is proceeding into the reasons for the mal-functioning of the standard single point pyrometer equipment.

This report is issued with the authority of



Air Commodore,  
Commanding, A. & A.E.E.

/Introduction....

## 1. Introduction

The high rate of failure of propeller driven engine cooling fans on Hastings aircraft, has necessitated the removal of that cooling aid from those aircraft operated by Transport Command. In consequence, the Air Ministry requested M. of S. to give consideration to the following:-

- (a) technical clearance for world wide operation without the fans fitted, or failing this
- (b) the development and production of cooling fans having a reasonable degree of mechanical reliability.

This request resulted in a number of meetings between the A.M., M. of S., Bristols and A. & A.E.E. It was not possible to reconcile a number of viewpoints put forward during these discussions. In particular, the cylinder temperatures observed by Transport Command during operation in the Middle East of Hastings aircraft without cooling fans differed from those to be expected when assessed on the basis of controlled engine cooling tests made in the tropics on a Hastings powered with Hercules 101 engines (with fans fitted), corrected for the estimated effect of the change to Hercules 106 engines without cooling fans. In consequence it was recommended that A. & A.E.E., with the assistance of Bristols, should conduct tropical engine cooling tests on a representative Hastings 2 aircraft, in the most adverse operational configuration of external load.

Subsequent to the allotment of Hastings C. Mk. 2 WD.476 for the trials, instructions were received not to proceed with the tropical tests pending further information from the Air Ministry. Cooling trials were however, made at A. & A.E.E., and the results of these tests form the subject of this report.

## 2. Description of aircraft relevant to tests

2.1. General. The aircraft is a standard Hastings C. Mk. 2 aircraft, powered with Hercules 106 engines, driving de Havilland 4-bladed hydromatic metal propellers of 13 ft. diameter (Type D.100/446/1.)

2.2. Engine particulars. Production Hercules 106 engines\* were installed as follows:-

P.O. No. 137469	P.I. No. 137485
S.O. No. 137477	S.I. No. 137468

Fuel injectors, Hobson R.A.E. type BI/SH.5/3 were fitted to each engine.

Normal and weak mixture bleed filter screens were incorporated as a safeguard against possible ingress of foreign matter. These filter screens do not affect the flow characteristics of the injectors. A standard ground tuning check was made and all engines were within prescribed limits (see Fig. 1).

The engine and propeller installations, in terms of the relevant aspects of cylinder cooling, were to the current modification standard. The cooling fans (Type DMFI/1) were removed from Nos. 1, 2 and 4 propellers for the comparative tests referred to later. The fan was retained on No. 3 propeller throughout the tests to provide an undisturbed datum. The spinner back plates and spinners were in situ throughout all the trials.

/The....

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\* The relevant differences between the Hercules 106 and 101 engines are:-

- (a) Take-off and operational necessity boost is  $8\frac{1}{2}$  lb./sq.in. for the 101, compared with 10 lb./sq.in. for the 106.
- (b) The 101 engine was tuned to the prescribed limits (common to both series) with an open exhaust, whereas the 106 engine was tuned to these limits with the correct exhaust system fitted.

At the respective take-off power rating the specific fuel consumption of the 101 engine with the correct exhaust system, is estimated to be 0.039 B/BHP/ greater than that of the 106 engine with a similar exhaust system.

The air intake system was standard, allowing selection of rammed cold air, rammed clean air, or warm air.

The engine limitations declared for the Hercules 106 engine in Eng.R.D.1(b) certificate ref. 7/Eng/3894 dated 7.12.51, are:-

<u>Power condition</u>	<u>R.P.M.</u>	<u>Boost</u> <u>lb./in<sup>2</sup></u>	<u>Cyl.</u> <u>temp. °C</u>	<u>Engine in oil</u> <u>temp. °C</u>
Take-off and operational necessity (5 min. limit)	2800	+10	310	100
Intermediate and max. emergency cruise	2400	+6	300	90
Max. continuous	2400	+6	300	80
Max. continuous with weak mixture	2400	+2½	300	80

2.3. Oil coolers. Lawrence coolers to Drg. JWL.131 Issue 3, fitted to Nos. 1, 2 and 3 engines; Serck cooler to Drg. No. W.S.11440 Issue 4, fitted to No. 4 engine.

#### 2.4. Test instruments

(a) Cylinder head temperatures were measured at all front row positions of each of the four engines, and at all rear row positions on No. 2 engine only. Elliott type gauges with ice-cold junctions were used throughout. No. 14 cylinder temperature gauges were located at the flight engineer's station but all others were mounted in an automatic observer. For certain tests, the standard single point\* pyrometers were connected to No. 14 cylinder of each engine

(b) Air temperature was measured on a balanced bridge type thermometer.

(c) Kent displacement type flowmeters were fitted to all engines, the impulses from these being received by standard gallons gone counters, flashing lights, and direct reading indicators, the latter located in the automatic observer.

(d) The standard pilots and flight engineer's instruments (previously calibrated) were used for all test work, but No. 2 engine r.p.m. and boost, together with an altimeter, A.S.I. and clock were duplicated in the automatic observer.

2.5. Loading. All tests were made from a take-off weight of 80,000 lb. With the exception of tests mentioned in the succeeding paragraph, no external load was carried.

The tests with external load were, for convenience, effected with 20 supply containers OLE Mk. 3 carried on racks under the fuselage and inboard wing section. This configuration was the nearest practicable approximation to the worst drag case of the Hastings aircraft.

### 3. Scope of tests

All tests were made in M. Supercharger gear.

Flight tuning checks at take-off, intermediate and max. continuous weak mixture power settings were made before commencing the cooling tests, and were repeated towards the end of these tests.

The cooling tests covered ground cooling, take-off and climb at take-off power for 5 mins, followed by climb at intermediate power to 8,000 feet. Tests in level flight at maximum weak mixture power were then made at 8,000 feet, followed by a shallow descent to approx. 1,000 feet, at which height a dropping run was simulated. Repeat tests were made as indicated in the following table.

/Table....

\* Thermocouple:- Store Ref.: 103542. Bristol Part. No. 139037.

Condition	No. of tests made.	Containers on or off.	Cooling fans on or off.	Cowl gill setting.
Ground cooling for 10 mins. at 1400 r.p.m.	2	Off	On	Full open
	2	Off	Off	Full open
Take-off and climb at take-off power for 5 mins. at 125 knots I.A.S.	4	Off	On	Full open
	2	Off	Off	Full open
	1	On	Off	Full open
Climbs at intermediate power from end of take-off power, to 8,000 ft. at 130 knots I.A.S.	2	Off	On	Full open
	2	Off	Off	Full open
	1	On	Off	Full open
Level flight at 3,000 ft. at max. continuous power, weak mixture.	2	Off	On	Shut
	2	Off	Off	Shut
	1	On	Off	( $\frac{1}{2}$ open on 2, 3, and 4.)
				(Full open on 1.)
Dropping run at 1,000 ft., at 2400 r.p.m. at 115 knots I.A.S.	1	On	Off	$\frac{1}{2}$ open on 1 and 2.
				Shut on 3 and 4.

✓ Fan on No. 3 engine for all tests.

During the ground cooling tests, recordings were taken each 3 minutes. During take-off tests, recordings were taken each 10-15 seconds until 1,000 ft. altitude was reached. During continuation of climb at take-off power recordings were taken at 500 ft. intervals, then at 1,000 ft. intervals after throttling back to intermediate power. Recordings in level flight were taken at the end of 10 minutes, by which time the cylinder temperatures were stabilised.

#### 4. Results of tests

4.1. General. The cylinder temperatures have been corrected to the I.C.A.N. standard of air temperature. Unity response of cylinder temperature to air temperature has been assumed in making that correction. The validity of that assumption, within the probable limits of the true value of the correction factor, is not important in terms of either the standard to which the results are corrected, or the comparisons made between different conditions; this is because the ambient air temperature on test was at no time more than 3°C below or above the I.C.A.N. standard.

All results quoted for a given condition of operation (c.g. power setting, configuration) are on the basis of mean values. Repeatability was normally within the order of 5°C or less but in some cases as much as 10°C was encountered; this excludes conditions of an essentially transient nature such as the opening-up period during take-off.

Cylinder temperatures are quoted to the nearest 5°C in the succeeding paragraphs.

4.2. Tuning characteristics. These results are plotted in Figure 1 and compared with the nominal fuel flow limits.

4.3. Ground cooling. The maximum cylinder head temperatures obtained, with cooling fans, at 1400 r.p.m. with propellers on the fine pitch stops, using clean air and 'H' gear with the gills fully open, were well within the

/relevant....

relevant limitations of 300°C (maximum continuous) and 230°C (recommended maximum before commencing take-off) with cooling fans fitted. Without the cooling fans, changes of temperature distribution occurred, with attendant increases in the maximum cylinder head temperatures which, however, were still well within the aforementioned limitations. Polar diagrams showing the temperature distribution at these conditions are given in Fig. 2.

4.4. Take-off and climb: The results are as follows:-

(i) Take-off and initial climb. Figs. 3A to 3D show curves of the highest cylinder temperature on each engine against time, zero time being that at which the aircraft brakes were released. With one exception, no particular attempts were made to obtain specific cylinder temperatures before starting the take-off, and any differences in starting temperature between various tests were reflected to a less extent on attaining safety speed (125 knots I.A.S.) at about 1 min. after release of brakes. Within 2 mins. of commencing the take-off, these effects were no longer evident, the engines by this time having settled down to stabilised conditions, under which, altitude was the only variable affecting cylinder temperatures.

These curves also show the effect of removing the cooling fans from Nos. 1, 2 and 4 engines in terms of the hottest cylinder in that configuration. The maximum cylinder head temperatures at the take-off speed were some 15° to 20°C greater with the fans removed, but thereafter the difference became progressively less. During the tests in which 20 containers were fitted externally, the time to attain safety speed increased by about 5 to 10 secs. but this increase had no significant effect on the maximum cylinder head temperatures, regardless of whether the cooling fans were fitted or not.

Polar diagrams showing the cylinder temperature distribution of each engine at a point approximating to the stage at which the aircraft was climbed away at the safety speed of 125 knots I.A.S. are given in Fig. 4, the effect of removing the cooling fans is also illustrated in that Figure.

(ii) Sustained Climb. Fig. 5 shows curves of the highest cylinder temperatures on each engine against height, i.e. from a point approximating to the termination of Figs. 3A to 3D, to the end of the 5 minute period at take-off power, and subsequently to 8,000 ft. at intermediate power.

Due to differences in height at which the engines were throttled back to intermediate power, stabilised cylinder temperatures are only shown between 7,000 and 8,000 ft.

Cylinder temperatures increased with height while at take-off power. At 4,500 ft. the higher altitudes common to all tests before throttling back to intermediate power, the highest cylinder temperature reached the relevant limitation of 310°C on Nos. 1 and 4 engines with cooling fan on, and exceeded the limitation by 10°C with fan off on Nos. 1, 2 and 4 engines.

The maximum cylinder temperature at intermediate power in the stabilised height range, 7,000 - 8,000 ft.; were within the limitation of 300°C in all instances.

Figs. 6 and 7 show polar diagrams of the cylinder temperature distribution on each engine at 4,500 ft. (take-off power) and at 8,000 ft. (intermediate power) respectively. The diagrams also show the effect of removing the cooling fans from Nos. 1, 2 and 4 installations, in terms of cylinder temperature distribution and highest cylinder temperatures.

The carriage of the 20 external containers did not significantly effect the cylinder temperatures.

4.5. Level flight at max. continuous power, weak mixture, at 8,000 feet. Polar diagrams for this condition are shown in Fig. 8. Removing the cooling fans caused higher cylinder head temperatures but these were well within limits with the aircraft clean and cooling gills closed.

/Figure 9.....

Figure 9 shows polar diagrams of cylinder temperatures with the fans of numbers 1, 2 and 4 installations, and the 20 cannisters fitted externally. The increase in temperature of the hottest cylinder due to the large loss of speed experienced with the containers fitted, was estimated theoretically to be about 25 - 30°C. The tests tended to confirm this estimate, and varying amounts of gill opening were necessary to keep the maximum cylinder head temperatures within the limitation of 300°C.

4.6. Level flight at 2400 r.p.m. at 1,000 feet at 115 knots I.A.S. This "dropping run" is of significance only when carrying the 20 external containers. In this configuration and using 20° flap, a boost pressure of about - 1 lb/sq.in. was required to give the desired I.A.S. of 115 knots. Polar diagrams for this condition (fan off Nos. 1, 2 and 4 installations) are shown in Fig. 10. Cylinder temperatures were high, requiring half gill opening on some engines to keep within the limitations of 300°C.

## 5. Discussion of results

5.1. Effect of removing cooling fans on cylinder temperatures. The effects are summarised below:

### Containers not fitted

Test conditions		Increase in max: cyl: temp: due to removing fans (°C)				Number of hottest cylinder					
Manoeuvre	Gills. Air Intake	No.	No.	No.	Mean	No.1	Eng.	No.2	Eng.	No.4	Eng.
		1	2	4	Inc.	Fan	Fan	Fan	Fan	Fan	Fan
						ON	OFF	ON	OFF	ON	OFF
Ground cooling at 1400 r.p.m.	Open. Clean.	20	5	25	15	2	12	1&7	12	2	12
Take-off at safety speed; take-off power.	Open. Clean.	15	15	20	15	12	12	8	2	12	14
Climb at 125 kts. at 4,500 feet. (near end of 5 mins); take-off power.	Open. Clean.	10	25	10	15	2	2	3	2	12	14
Climb at 130 kts. at 3,000 feet; intermediate power.	Open. Ram.	0	10	10	5	14	14	1	1&2	14	14
Level flight at 8,000 feet; max. continuous power, weak mixture.	Shut. Ram.	10	15	0	10	2	2	1	1	2	2&14

These results are in good agreement with those obtained on other comparable installations at the A. & A.E.E.

5.2. Comparison of cylinder temperatures measured by the standard and test pyrometers. A comparison is made, using notation as follows:-

- Cylinder head temperature of No. 14 cylinder measured by the Standard single point pyrometers.
- Cylinder head temperature of No. 14 cylinder measured by test pyrometers.
- Cylinder head temperature of the hottest cylinder, measured by test pyrometers.

/cooling....

Cooling fans off Nos. 1, 2 and 4 engine installations, gills fully open except in level flight at 8,000 feet, when they were shut:  
Containers not fitted.

Manoeuvre	A - B (°C)					A - C (°C)				
	Engine No.				Mean Value	Engine No.				Mean Value
	1	2	3	4		1	2	3	4	
Ground run at 1400 r.p.m.	-15	-15	0	-20	-10	-20	-25	-5	-30	-20
Take-off at safety speed; take-off power.	-25	-30	0	-15	-15	-35	-35	-10	-15	-25
Climb at 125 knots at 4,500 feet, (near end of 5 mins) take-off power.	-35	-20	-10	-20	-20	-45	-50	-25	-20	-35
Climb at 130 knots at 8,000 feet; intermediate power.	-35	-30	-10	-15	-20	-35	-35	-10	-15	-25
Level flight at 8,000 feet; max. continuous power, weak mixture.	-30	-35	-10	-10	-20	-55	-45	-30	-10	-35

The mean values of A - B are similar to results obtained on a Hastings aircraft powered with Hercules 101 engines at A. & A.E.E. and T.E.U. (See 17th Part of AEE/843). The tests on that Hastings aircraft also showed that number 14 cylinder, to which the standard pyrometer was fitted, was not the hottest cylinder in every case; a similar result was obtained on a Varsity. (See 7th part of AEE/873).

The reasons for incorrect indications of cylinder temperatures given by the single point pyrometers is not known to date; this is to be the subject of a separate investigation.

It is significant, however, that the errors (mean values) in cylinder temperature indications tend to become greater with progress of the flight plan, i.e., the errors are a minimum during the ground run, rising to a maximum before throttling-back to continue the climb at intermediate power, and thereafter remaining sensibly constant. This characteristic of error may be due to the influence of temperature gradients and changes in those gradients, across the fireproof bulkhead (which carries a form of plug and socket connection for the pyrometer leads), reacting unfavourably on the electrical characteristics of the pyrometry. The basis for believing that there are material changes in temperature gradient is founded on the supposition that the engine bay forward of the fireproof bulkhead is being generally heated as the flight progresses, until it reaches a near stable temperature around the throttle-back point on the climb, while the temperature to the rear of the bulkhead remains sensibly constant at a materially lower temperature. The effect of such unequal heating on the behaviour of the pyrometry will be included in the investigation referred to above.

The potential dangers of incorrect indications (negative errors) of the hottest cylinder temperature of the magnitude shown above (A - C) would appear to be obvious. The following is indicative of those dangers.

(a) It is assumed that, among other reasons, the pyrometers are installed for use by aircrew as a guide as to when to adjust the cowl gills to keep the cylinder temperatures within the prescribed limitations; observing the

/principles....

principles that minimum gill opening, commensurate with cooling requirements, should be used for reasons of aerodynamic cleanliness and hence optimum performance. If such a procedure is used in the Service, it would be reasonable to expect serious overheating of the engine, in terms of the cylinder temperature limitations declared for the Hercules 106 engine, particularly with the aircraft carrying external stores in hot climates.

(b) Transport Command would appear to be justified by their multitude of indications of cylinder temperature observed during operations of Hastings aircraft in hot climates in believing that the cooling level of the Hercules 106 engine is quite adequate for operating under conditions of high air temperature. This belief could be such that, if the failure rate of cowl gill components (e.g. gill motors) becomes unreasonable, they may decide to make the gills inoperative, i.e., fixed in the closed position. The dangers attendant upon such a hypothetical case are again evident in terms of the limitations declared for the Hercules 106 engine.

5.3. Positioning of single point pyrometer. It is clearly impracticable to select any one cylinder that is always the hottest under the varying conditions of operation, since changes in temperature distribution are brought about by such factors as:-

- (a) changes of engine setting at constant height,
- (b) changes of height at constant engine setting,
- (c) changes in ambient air temperature,
- (d) changes of gill setting,
- (e) engine tuning tolerances.

Furthermore, variations of temperature distribution will undoubtedly occur between nominally identical engines and/or by virtue of different locations on the aircraft.

The results of the present tests have, however, been examined to determine if number 14 cylinder is the best choice for indicating the highest cylinder head temperature under the conditions of test covered in this report. This results in the following:

- (i) Using all the results, fans on and off. The cylinder which more often experiences the highest temperature, is No. 2; it is not, however, greatly superior to No. 14.
- (ii) Using the results with fans off. The result is similar to (i), but with greater emphasis on No. 2 cylinder as the more representative cylinder.
- (iii) Using only the results of the two most critical working cases, fans off. Number 2 cylinder is the hottest in both instances.

The foregoing agrees with somewhat meagre results obtained at this Establishment on other similar engine installations.

5.4. Assessment of suitability of cylinder cooling for operating under conditions of I.C.A.N., temperate summer, and tropical summer standards of air temperature\*, in terms of the current cylinder temperature limitations. The following is to be noted in relation to this assessment:-

(i) Tests on WD.476 were, in general, intended to be made with an external configuration representative of the worst drag case, e.g., two jeeps and six containers carried externally. Circumstances made it necessary, however, to approximate to that condition on test, by the carriage of twenty containers. The aircraft's performance in each of these configurations is given in the 4th Part of AAE/843/1/P. That data has been used as a basis for estimating the effect of the reduced performance due to the carriage of the mixed load of jeeps and containers, on cylinder cooling. This results in:-

/(a)....

\*I.C.A.N.:- 15°C at sea level with associated lapse rate.  
Temperate Summer:- 27°C at sea level with associated lapse rate.  
Tropical Summer:- 41°C at sea level with associated lapse rate.

- (a) negligible effect on cylinder temperatures during ground running, take-off, and climb.
- (b) a rise in cylinder temperatures of about 5°, in level flight at 8,000 feet at maximum continuous power (weak mixture) and in level flight at 1,000 feet using a power setting to achieve the desired dropping speed of 115 knots, I.A.S.

The assessment of the suitability of cylinder cooling includes an allowance for (b).

(ii) Tests made over a range of air temperature on other engine installations, indicates that the correction to cylinder temperature for air temperature will not be less than  $1.0 \Delta T$  when using cruising powers in the weak mixture range, and is probably of the order of  $0.7 \Delta T$  at take-off and intermediate powers.

The assessment is therefore given on the basis of:-

- (a)  $1.0 \Delta T$  for all tests; this conforms with the present requirements of A.P. 970.

also (b) using  $0.7 \Delta T$  for those tests at take-off and intermediate powers.

The assessment is made in tabular form below, as the differences (to the nearest 5°C) between the temperature of the hottest cylinder of the hottest engine and the appropriate limitation, for the three standards of air temperature.

"M" Supercharger

Test conditions					Difference between hottest cylinder temperature and limitation, °C.				
Manoeuvre	Power Setting	Cowling and air intake	Ext. load on or off	Fans on or off	N I.C.A.N.	Temperate Summer		Tropical Summer	
						$1.0 \Delta T$	$0.7 \Delta T$	$1.0 \Delta T$	$0.7 \Delta T$
On attaining safety speed at take-off (125 kts. I.A.S.)	Take-off	Full open. Clean.	On or Off	On Off	-25 -10	-15 0	-5 0	0 +15	-5 +10
Climb at 4,500 ft. at 125 kts. I.A.S. (towards end of 5 min. from start of take-off)	Take-off	Full open. Clean.	On or Off	On Off	0 +10	+10 +20	+10 +20	+25 +35	+20 +30
Climb at 8,000 feet at 130 kts. I.A.S.	Intermediate	Full open. Ram.	On or Off	On Off	-15 -5	-5 +5	-10 0	+10 +20	+5 +15
Level flight at 8,000 feet.	Max. contin. (Weak Mix.)	Shut. Full open. Ram.	Off On	Off	-25 -20	-15 -10	Not applicable	0 +5	Not applicable
Level flight at 1,000 ft. at dropping speed of 115 kts. I.A.S. mixture	At appropriate power, weak mixture	Half open. Ram.	On	Off	+5	+15		+20 +30	

/Contd.....

$\Delta T$  = the difference between the standard air temperature and the ambient air temperatures on test.

- / External load assumed to be 2 jeeps and 6 containers.
- These results are factual (the air temperature on test did not differ from the I.C.A.N. standard by more than  $\pm 3^{\circ}\text{C}$ ).

It is possible that Transport Command, in their routine operation of Hastings aircraft, do not invoke the use of take-off power for a period greater than that necessary to achieve a safe height following take-off, (up to about 100 feet), the engines then being throttled back to intermediate power. It is estimated that, under those conditions of operation:-

- (a) the maximum cylinder temperature at the throttle-back point would be about  $5^{\circ}\text{C}$ . greater than that obtaining at the take-off safety speed.
- (b) considering the take-off and climb to 8,000 feet as a whole, the maximum amount by which the temperature of the hottest cylinder would exceed the limitation with fans off, will be reduced to some 15 to  $20^{\circ}\text{C}$  under tropical summer conditions.

On the other hand, such a relaxation in cylinder temperatures would not be valid under circumstances such as an engine failure occurring on take-off, or when practising overshoots with simulated engine failure.

Tests on similar installations at this Establishment have shown that opening the gills fully at constant power setting is not necessarily the best method of achieving a reduction of cylinder temperature in level flight. It was found from these tests that, for the same loss of speed arising from opening the gills fully at constant throttle setting, a greater reduction (approximately  $5^{\circ}\text{C}$ ) of cylinder temperatures was obtained by throttling back with the gills shut. The adoption of such a procedure in lieu of using full gill opening in level flight at 8,000 feet should produce a similar beneficial result.

In the case of level flight at 1,000 ft., when it is required to achieve a speed of 115 knots, the combination of power and gill setting used is considered to approximate closely to the optimum for cylinder cooling. The characteristics of the gills are such that opening them beyond the position chosen (half open) would result in a fairly rapid increase of drag accompanied by an insignificant improvement in cylinder cooling at constant engine setting. Since increased power will then be required to maintain the speed of 115 knots I.A.S., this would probably result in higher cylinder temperature.

## 6. Conclusions

6.1. Standard single point pyrometers, and their location. The cylinder head temperature of No. 14 cylinder, to which the standard single point pyrometer is fitted on each engine, is incorrectly indicated by the standard pyrometer. This equipment indicates a cylinder temperature some  $20^{\circ}\text{C}$ , lower than that measured by test equipment.

No. 2 cylinder would be a better choice than No. 14, for locating the single point pyrometers, in terms of a cylinder which is most frequently the hottest cylinder under all the various conditions of operation.

The potential dangers associated with the unreliability of the present single point equipment, coupled with the impracticability of selecting a single cylinder which is always the hottest under all conditions, warrants consideration being given to the deletion of that equipment in its present form and the institution of a suitable drill for manipulation of the gills in terms of operating conditions and ambient air temperature. When the reasons for the mal-functioning of the single point pyrometers is known, and cures effected, the re-introduction of single point equipment would be justified; it should be located on a cylinder which is the most representative of the hottest cylinder for those conditions of operation giving rise to the highest critical cylinder temperatures.

/6.2....

6.2. Suitability of cylinder cooling in terms of the current cylinder temperature limitations. After taking into account

- (i) the probable manner in which Hastings aircraft carrying external stores are operated by Transport Command,
- (ii) methods of obtaining optimum cylinder cooling,
- (iii) corrections which are a closer approximation to the true rate of change of cylinder temperature with air temperature,
- and (iv) an external load representative of the worst drag case,

it is concluded, from the tests on WD.476 with cooling fans removed, that the current cylinder temperature limitations will be exceeded under tropical summer conditions by:-

- |  |       |
|--|-------|
| (a) Take-off   | 10°C  |
| (b) Climb  | 15°C  |
| (c) Level flight at 8,000 feet                             | 15°C  |
| (d) Level flight at 1,000 feet, (dropping speed 115 knots) | 30°C. |

With the cooling fans fitted, (d) is the only case likely to give rise to the limitations being materially exceeded, i.e., by about 15 to 20°C.

The frequency with which mechanical failures of the cooling fan installation has occurred on Hastings aircraft operated by Transport Command, suggests that their retention may introduce a hazard greater than that due to the increase of cylinder temperature arising from their removal.

6.3. Suitability of the cylinder cooling in terms of the experience obtained in Transport Command. It appears that Transport Command is successfully operating Hastings aircraft powered with Hercules 106 engines, without cooling fans, under near tropical conditions. These operations have presumably included Hastings aircraft in configurations similar to the worst drag case e.g. two Jeeps and six containers.

If this is correct, then,

- (a) on the basis of the results obtained on WD.476
- (b) assuming the conditions of test on WD.476, combined with the relevant assumptions made, reflect the manner with which Hastings aircraft are operated by Transport Command,
- and (c) assuming that similar low indications of cylinder temperature are displayed to the operators by the standard single point pyrometers (which may lead to the gills being closed when they should be open),

then it would appear that cylinder temperatures materially higher than the current limitations have occurred on numerous occasions.

This would be expected to give rise to an increase in the rate of engine or relevant component failure. To the best of our knowledge, however, this has not occurred. We would therefore suggest that, on the basis of the foregoing, the cylinder temperature limitations declared for the Hercules 106 engine can be materially exceeded with safety.

7. Further developments.

An investigation is proceeding into the reasons for the apparent malfunctioning of the standard pyrometer equipment.

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# HERCULES 10G

FIG. 1.

NOMINAL FUEL FLOW LIMITS FOR I.C.A.N. AIR INTAKE TEMPERATURES DERIVED FROM 'BRISTOL' CURVES FB. 180468 & 180479, COMPARED WITH ACTUAL FLOWS MEASURED IN LEVEL FLIGHT AND CORRECTED TO I.C.A.N. AIR INTAKE TEMPERATURES.

DETAILS OF STANDARD GROUND TUNING CHECK L.E. NORMAL TO WEAK MIXTURE R.P.M. DROP:-

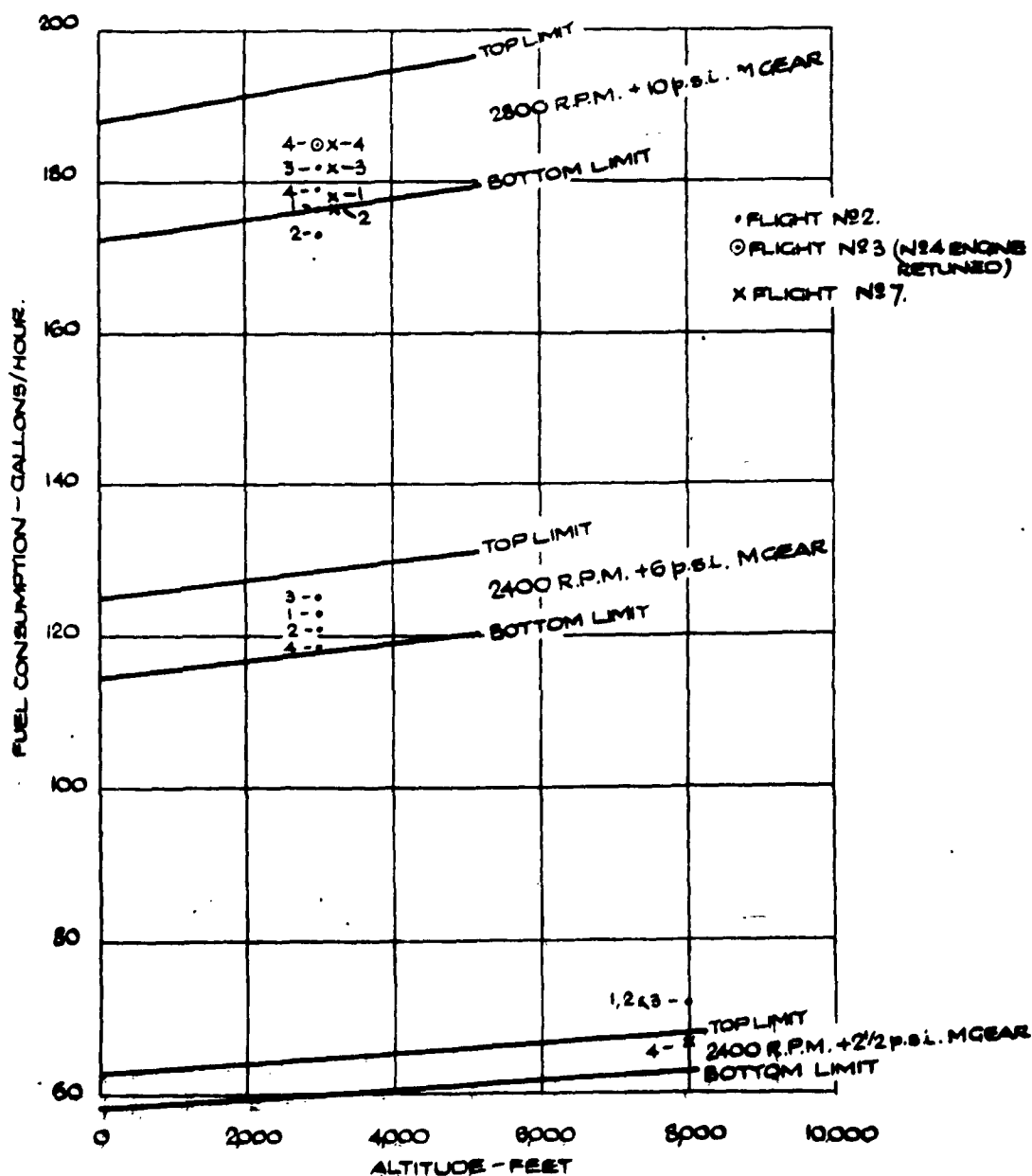
Nº1 ENGINE ~ 20 R.P.M. DROP (MID-LIMIT)

Nº2 ENGINE ~ 20 R.P.M. DROP (MID-LIMIT)

Nº3 ENGINE ~ 20 R.P.M. DROP (MID-LIMIT)

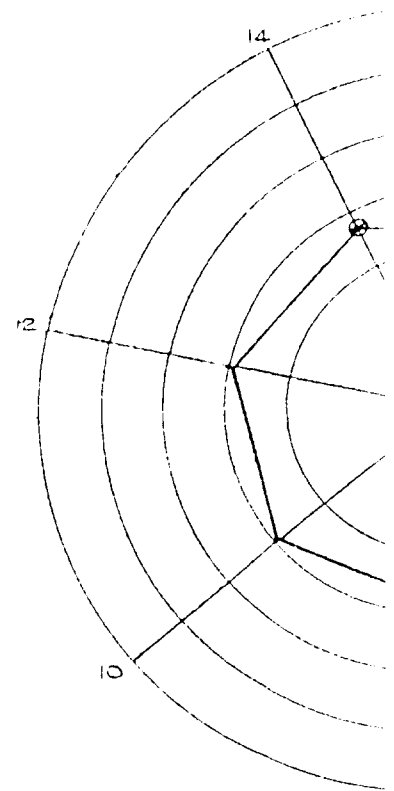
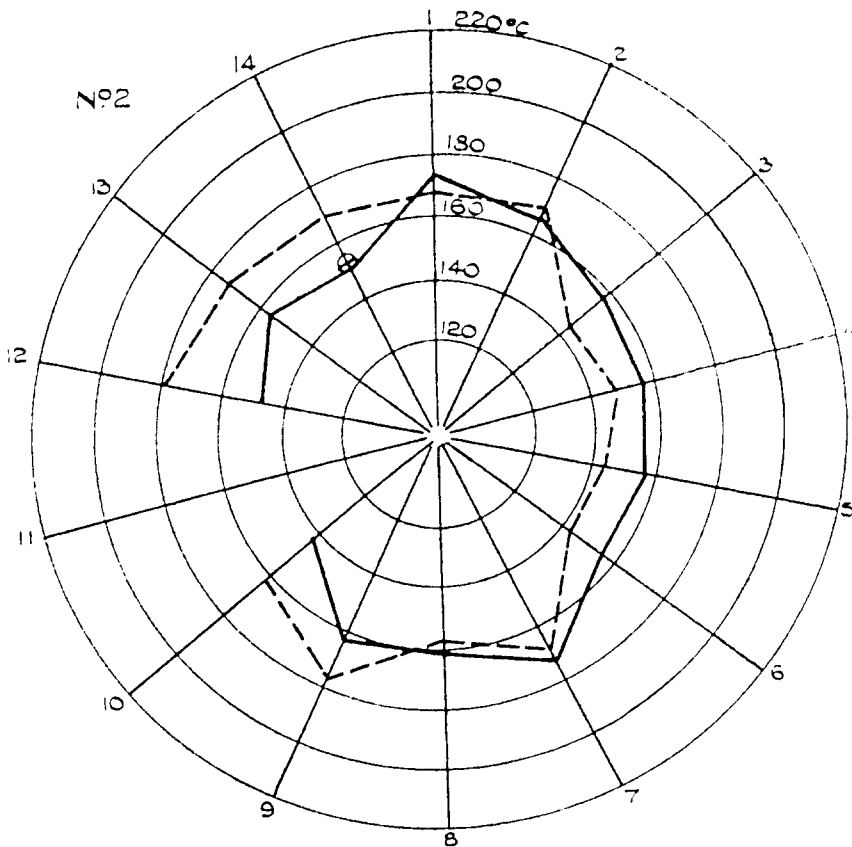
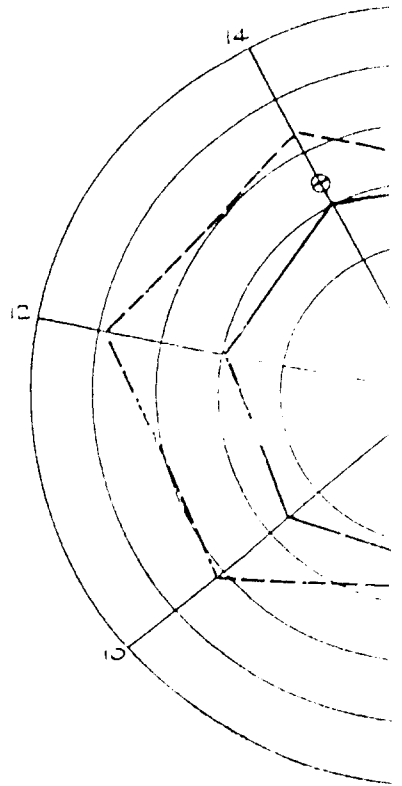
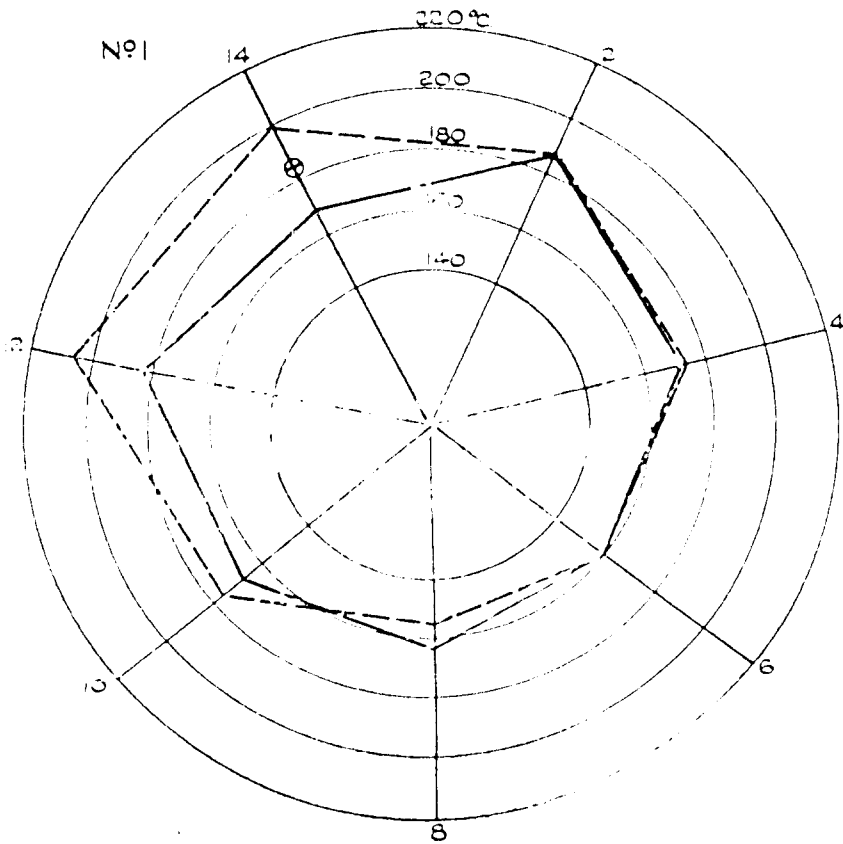
Nº4 ENGINE ~ ORIGINALLY NIL R.P.M. DROP (TOP LIMIT)

10 R.P.M. DROP AFTER WEAKENING 5 DIVISIONS ON NORMAL BLEED.  
RESET TO ORIGINAL VALUE AFTER FLIGHT Nº2.



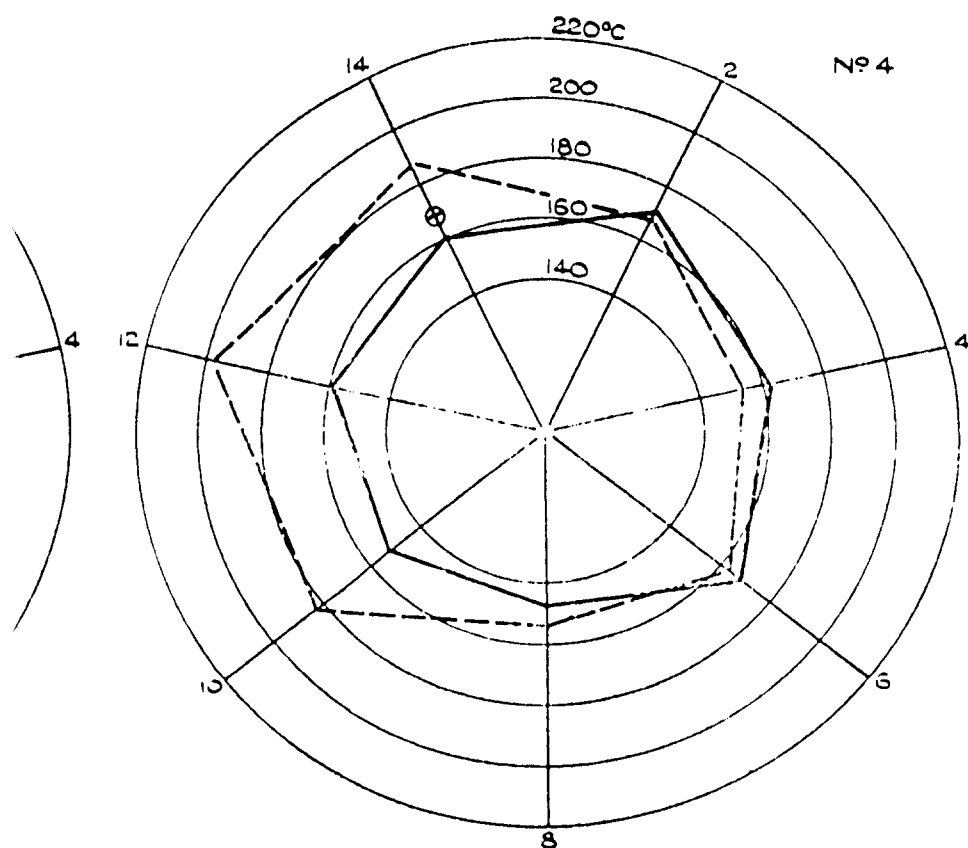
ENGINE TUNING

SK. Nº9A + 825 PART OF REPORT Nº2A.E.E. / 843/1 HASTINGS MK.2. W0476. TR. S.M. CH. D. LANG APP. 6466 for 509 P. 3-7-5



CYLIT  
 1400

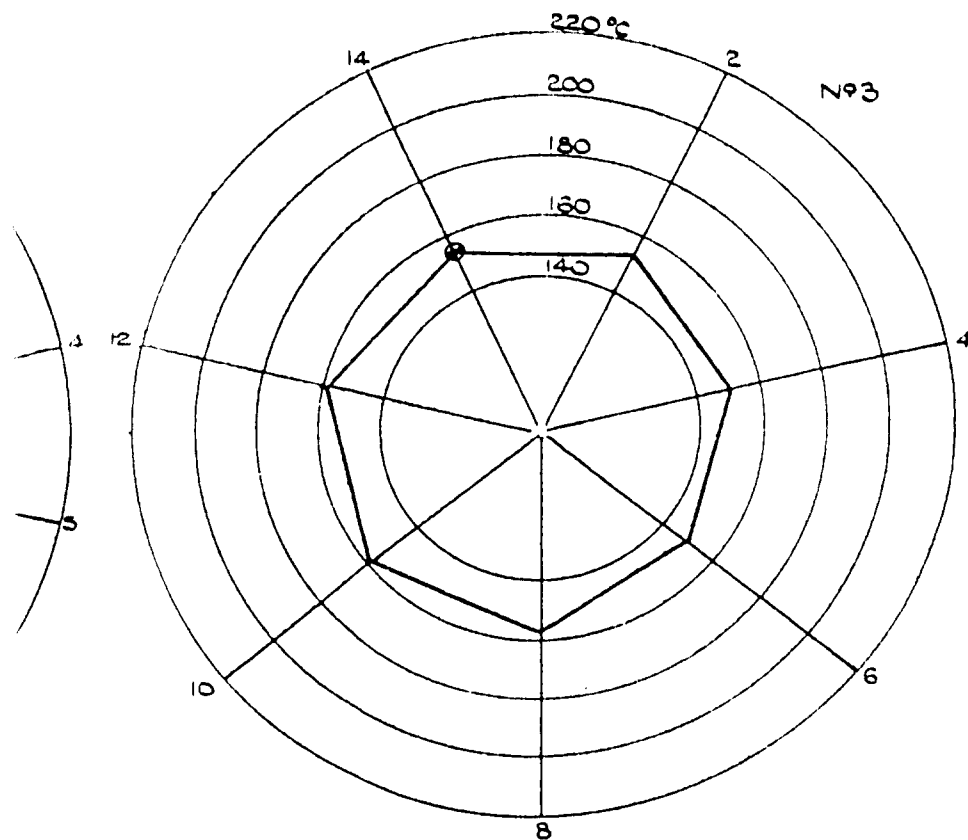
FIG.2.



CYLINDER HEAD TEMPERATURE  
LIMITATION = 300°C.

RECOMMENDED MAXIMUM BEFORE  
COMMENCING TAKE-OFF = 230°C.

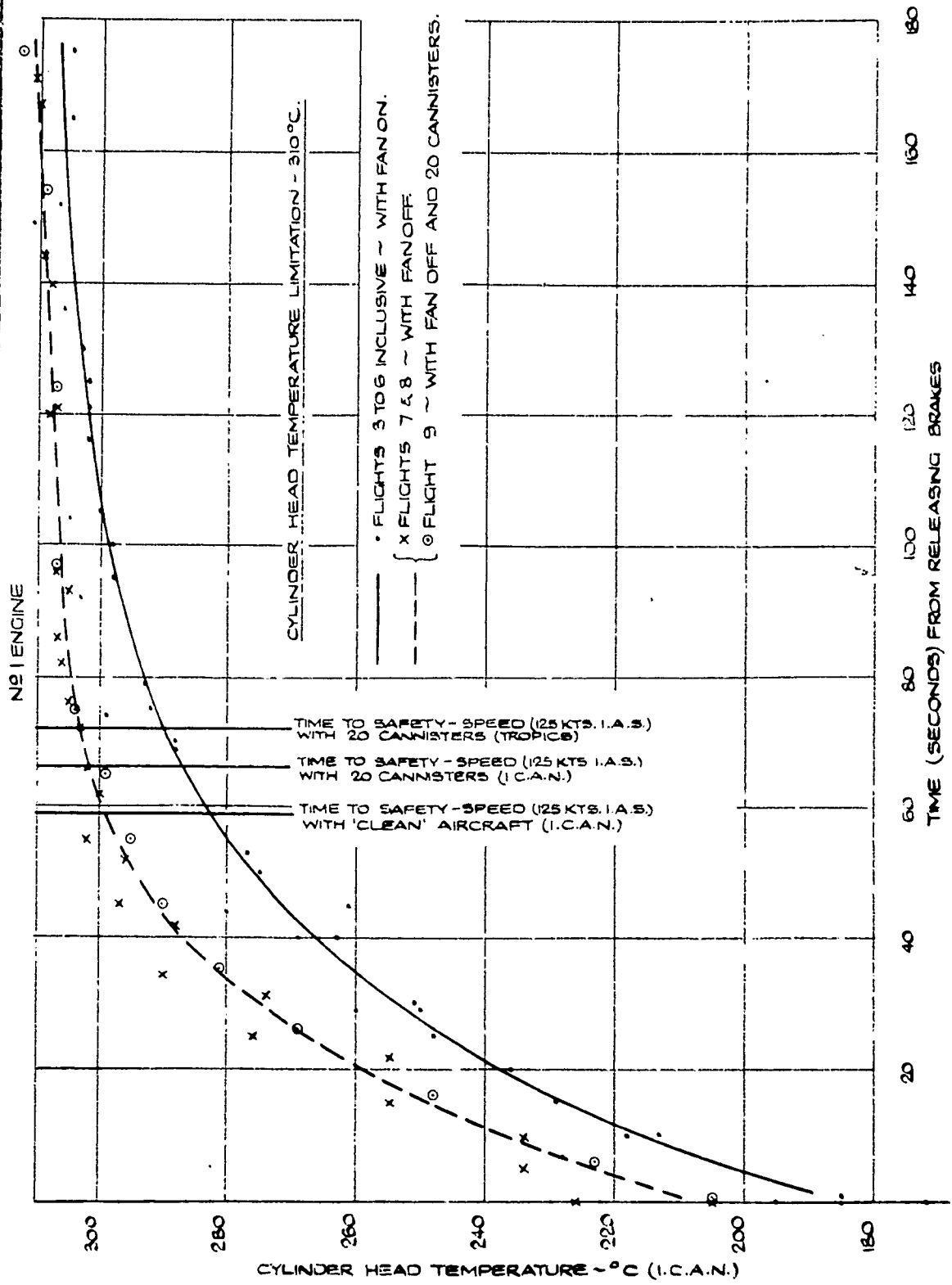
—— FANS ON  
--- FANS OFF (12/14 ENGINES)  
P ONBOARD PYROMETER ON  
NO. 2 CYLINDERS, WITH FANS OFF  
NO. 1, 2 & 4 ENGINES.



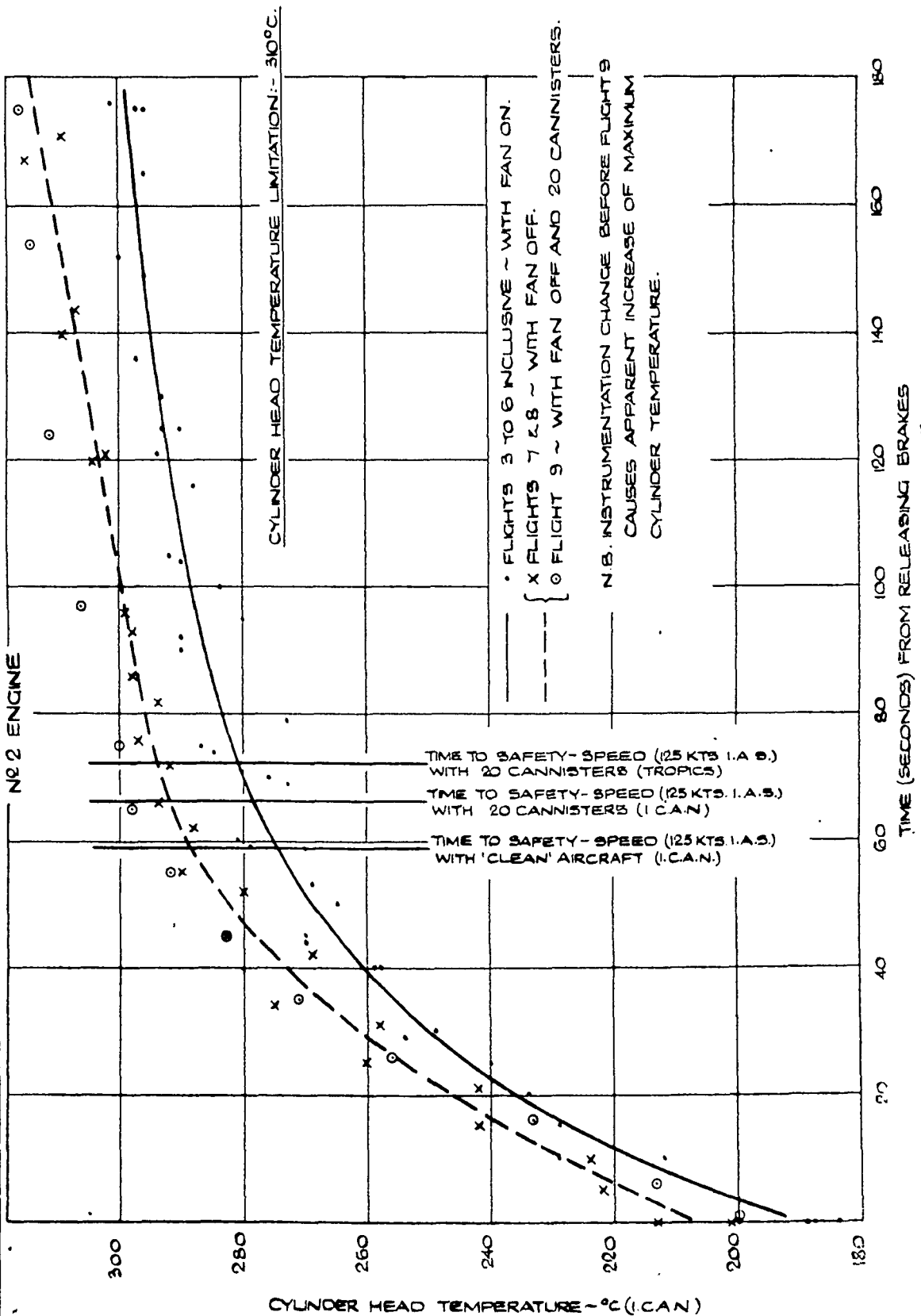
NB  
FRONT-ROW (EVEN-NUMBERED)  
CYLINDER HEAD TEMPERATURES  
MEASURED ON ALL ENGINES.  
REAR-ROW (ODD-NUMBERED)  
TEMPERATURES ON NO. 2 ENGINE ONLY

CYLINDER HEAD TEMPERATURE DISTRIBUTION IN CROSS-WIND GROUND RUN,  
1400 R.P.M. 50% MAXIMUM WITH PROPELLER ON FINE PITCH STOP  
CLEAN AIR. GILLS FULLY OPEN. "M" GEAR. (I.C.A.N.)

FIG.3A.

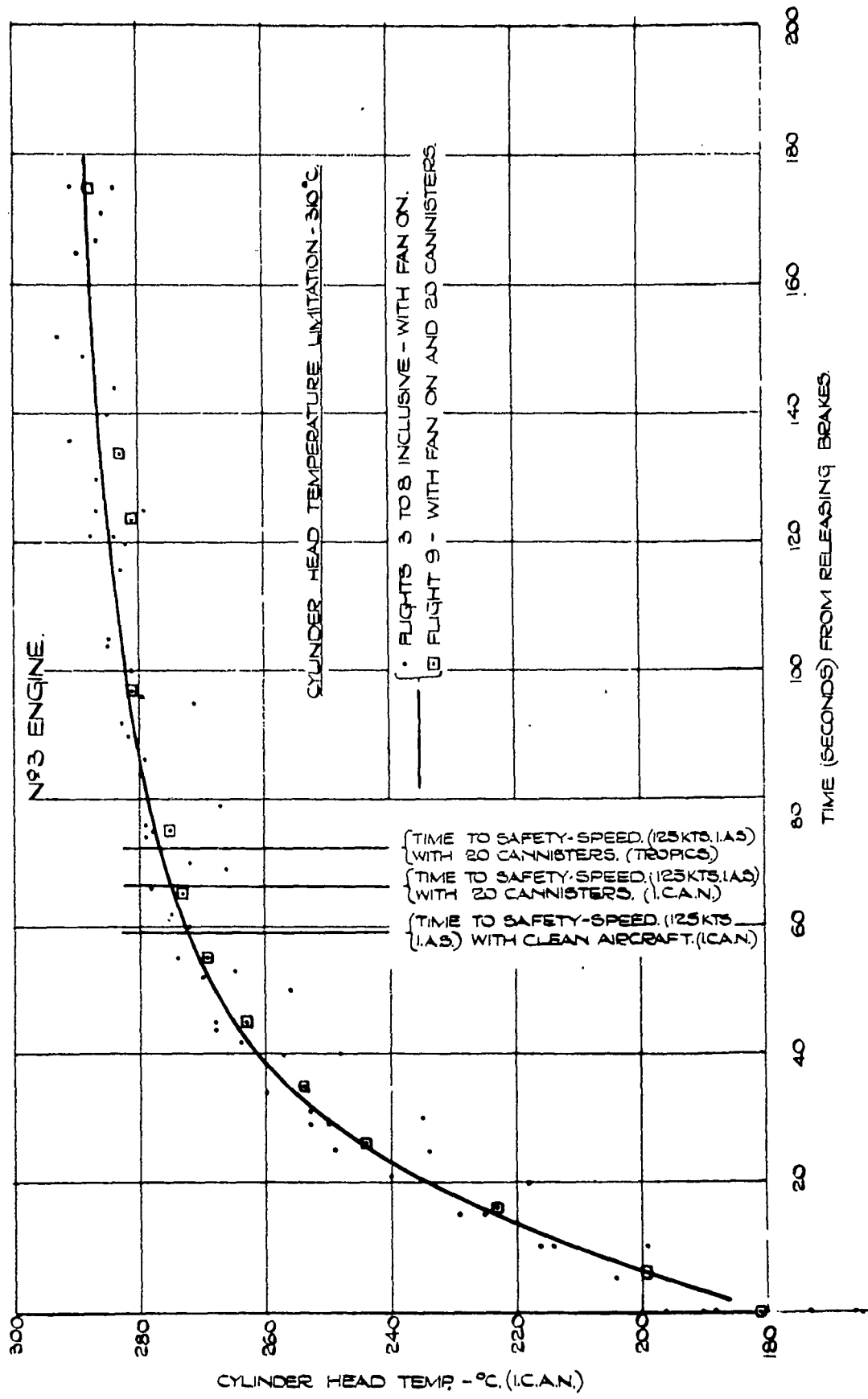


MAXIMUM CYLINDER HEAD TEMPERATURE DURING TAKE-OFF & INITIAL CLIMB AT TAKE-OFF POWER WITH GILLS FULLY OPEN; M GEAR. CLEAN AIR. (I.C.A.N.)



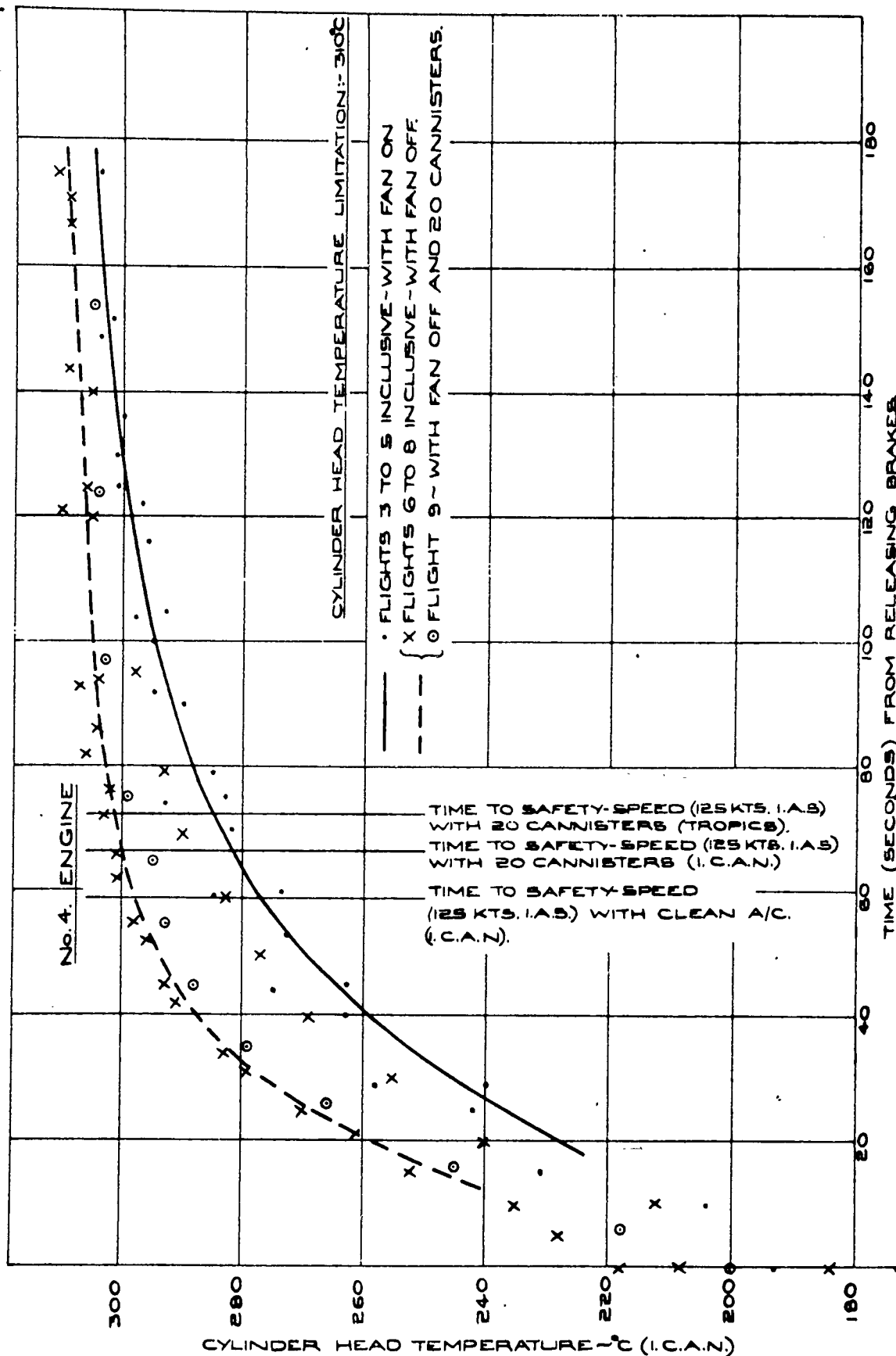
MAXIMUM CYLINDER HEAD TEMPERATURE DURING TAKE-OFF & INITIAL CLIMB AT  
TAKE-OFF POWER WITH GILLS FULLY OPEN; M GEAR. CLEAN AIR. (I.C.A.N.)

FIG.3C.

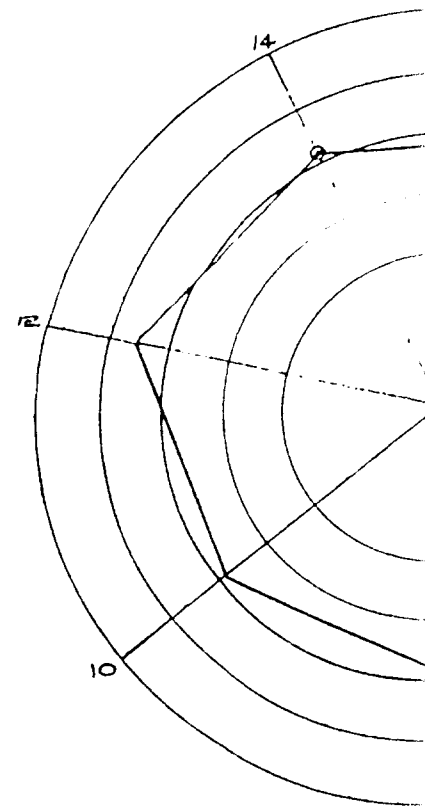
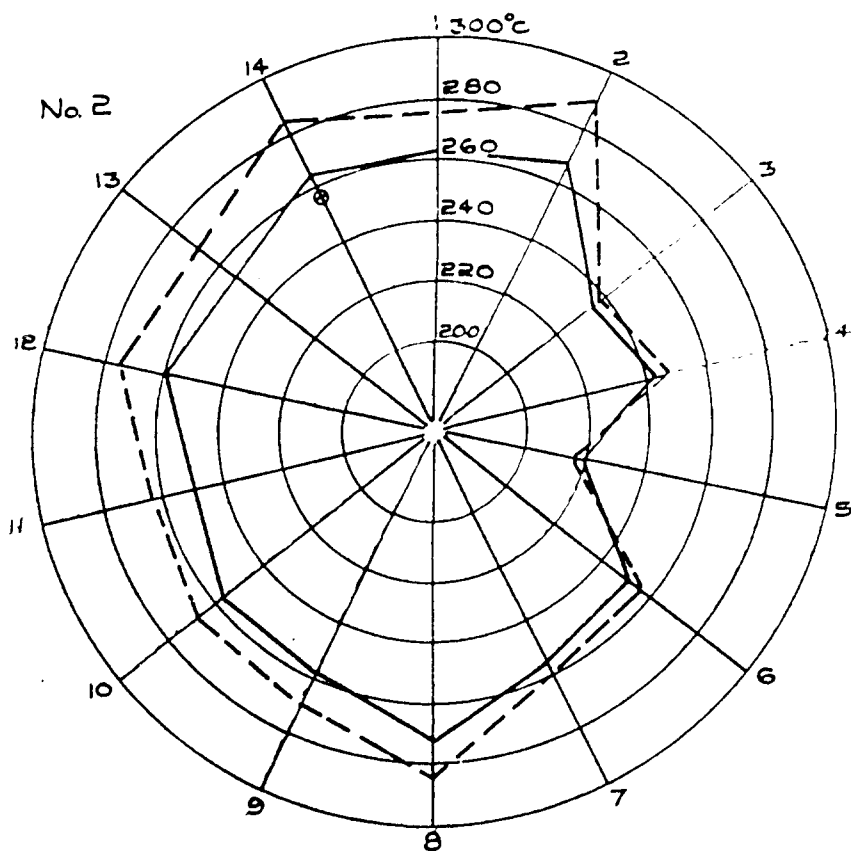
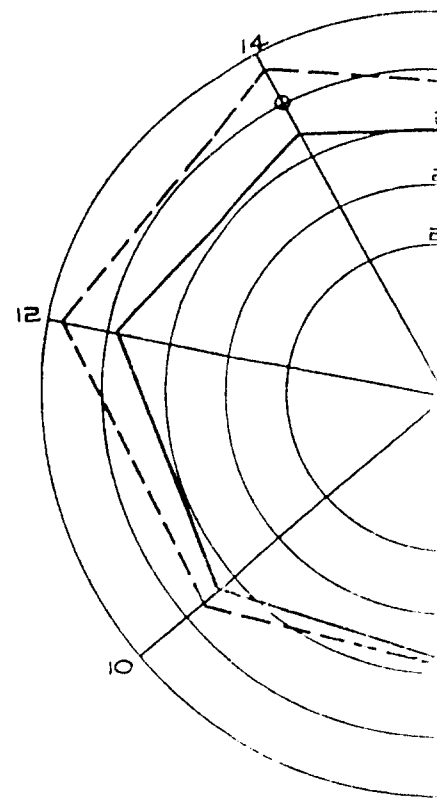
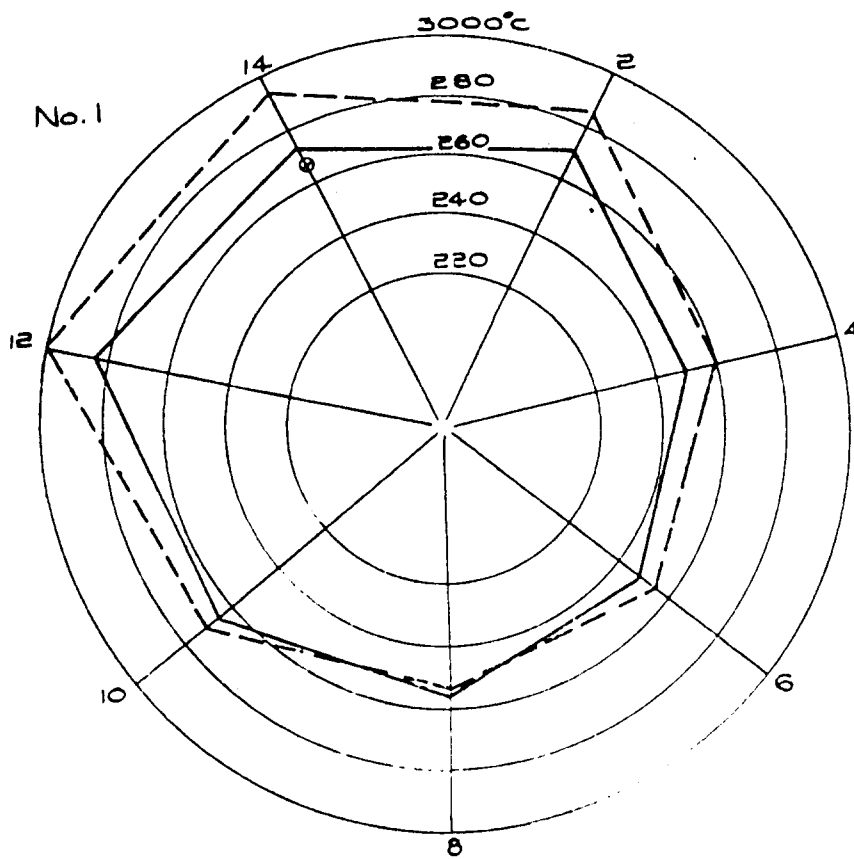


MAXIMUM CYLINDER HEAD TEMPERATURE DURING TAKE -OFF & INITIAL CLIMB AT TAKE-OFF POWER WITH GILLS FULLY OPEN; M GEAR, CLEAN AIR. (I.C.A.N.)

FIG. 3 D

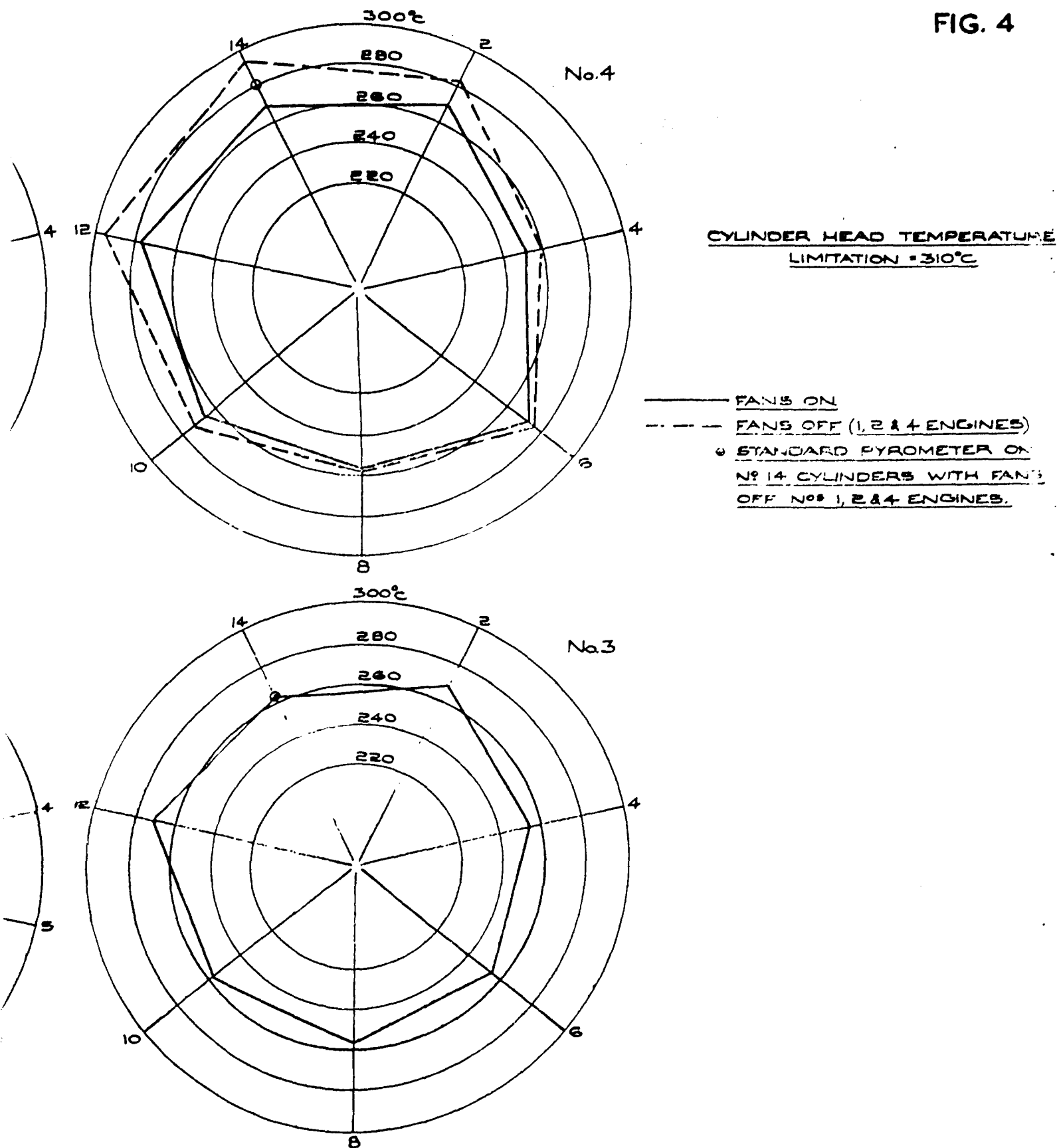


MAXIMUM CYLINDER HEAD TEMPERATURES DURING TAKE-OFF & INITIAL CLIMB AT TAKE-OFF POWER WITH GILLS FULLY OPEN "M" GEAR. CLEAN AIR. (I.C.A.N.)



CYLINDER  
(125 KNO)

FIG. 4



CYLINDER HEAD TEMPERATURE DISTRIBUTION ON ATTAINING SAFETY-SPEED (125 KNOTS I.A.S.) TAKE-OFF POWER. CLEAN AIR GILLS FULLY OPEN.  
M<sup>1</sup> GEAR (I.C.A.N.)

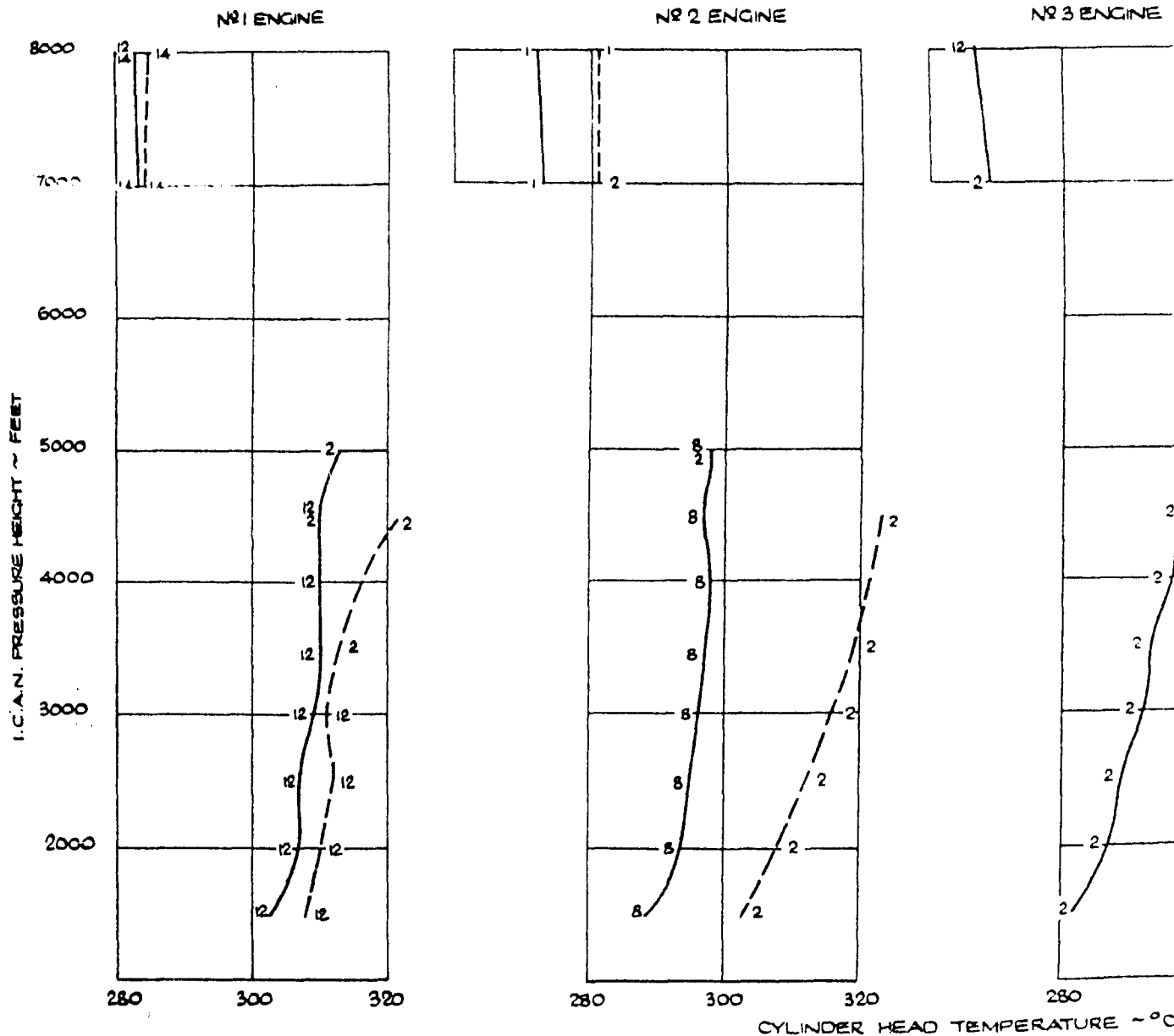
31-7-53  
 APP - *Hand* for Sof P  
 TR. S.M. CH. D. LANG  
 HASTINGS MK.2. WD.476  
 845/1

CYLINDER HEAD TEMPERATURE LIMITATION:-

- (a) TAKE-OFF POWER - 310°C.
- (b) INTERMEDIATE POWER - 300°C.

—— FANS ON.  
 --- FANS OFF.  
 (Nº 1, 2 & 4 ONLY)

FIGURES BESIDE CURVES REFER TO CYLINDER Nº



N.B. TAKE-OFF POWER FOR 4 1/2/5 MINUTES TO 4500/5000 FEET, FOLLOWING  
 CYLINDER HEAD TEMPERATURES NOT SETTLED BETWEEN ENG

MAXIMUM  
 CLEAN AIR  
 (RAM AIR)

HEAD TEMPERATURE LIMITATION:-

TAKE-OFF POWER - 310°C.

INTERMEDIATE POWER - 300°C.

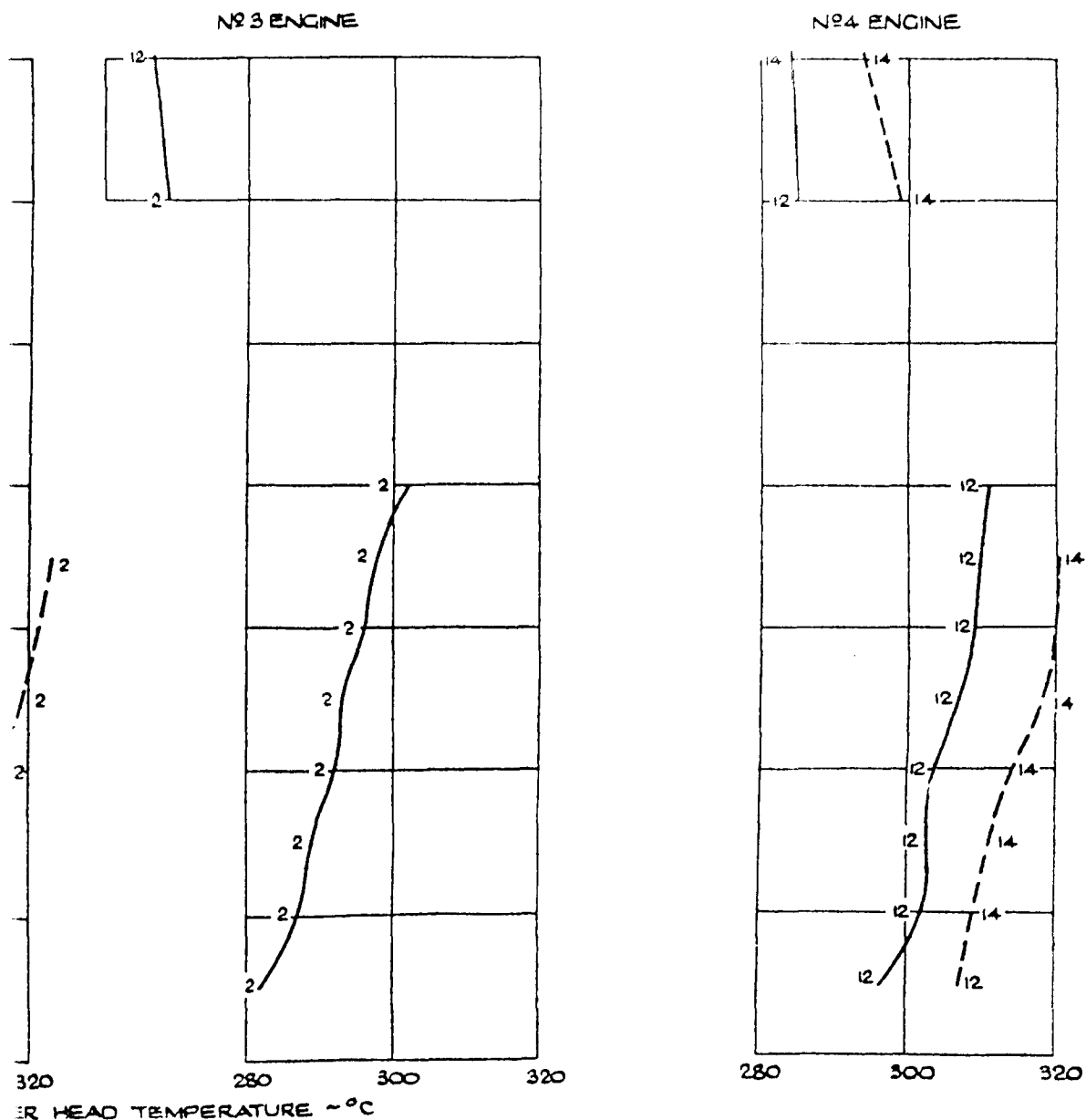
FANS ON.

FANS OFF.

(1,2,4 ONLY)

CURVES REFER TO CYLINDER NUMBERS.

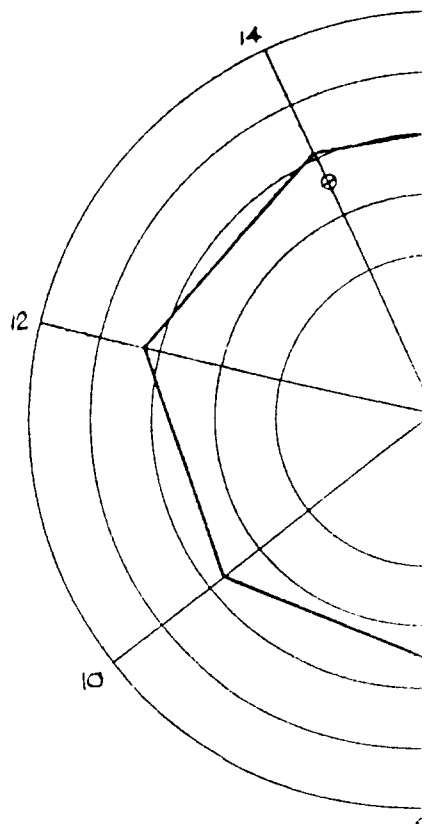
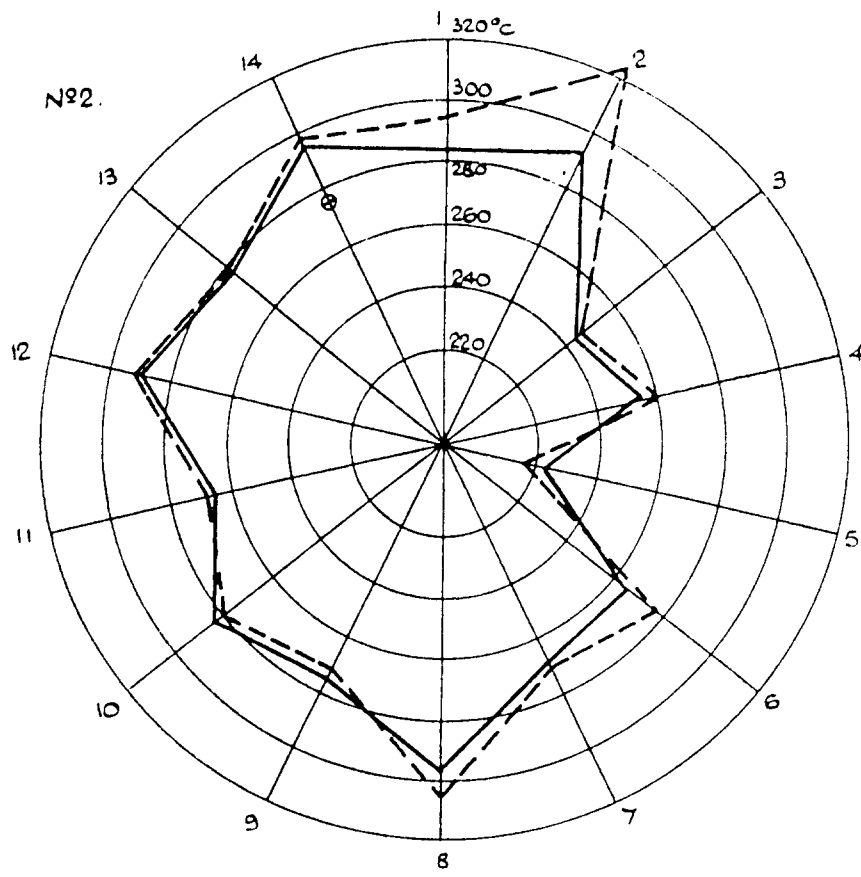
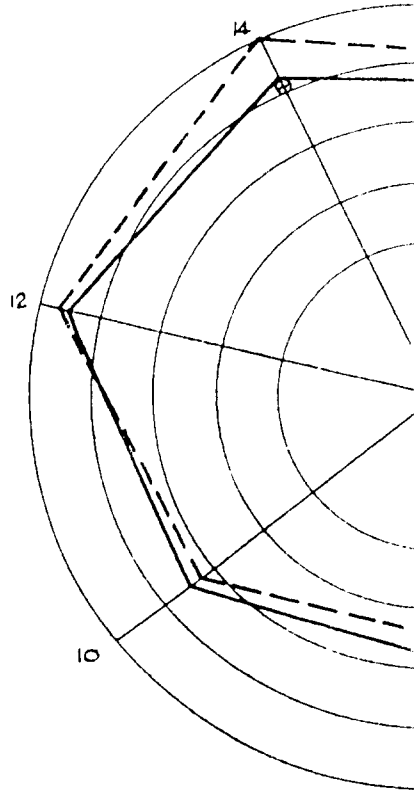
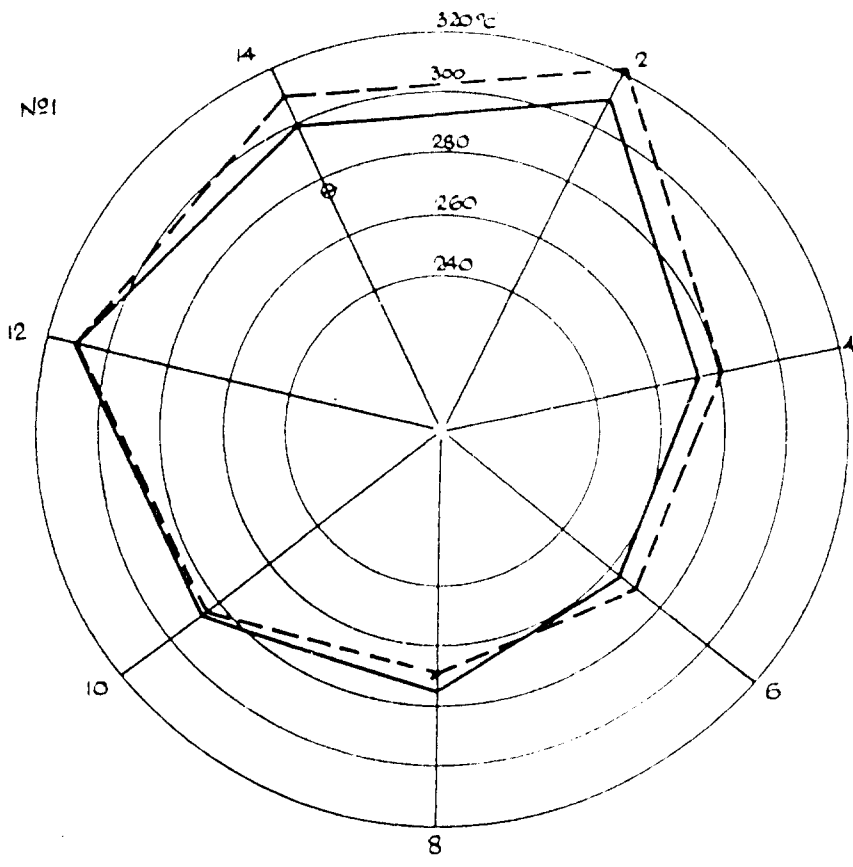
FIG. 5.



CLIMB TO 4500/5000 FEET, FOLLOWED BY INTERMEDIATE POWER, TO 8000 FEET.  
NOT SETTLED BETWEEN END OF TAKE-OFF POWER CLIMB AND 7000 FEET.

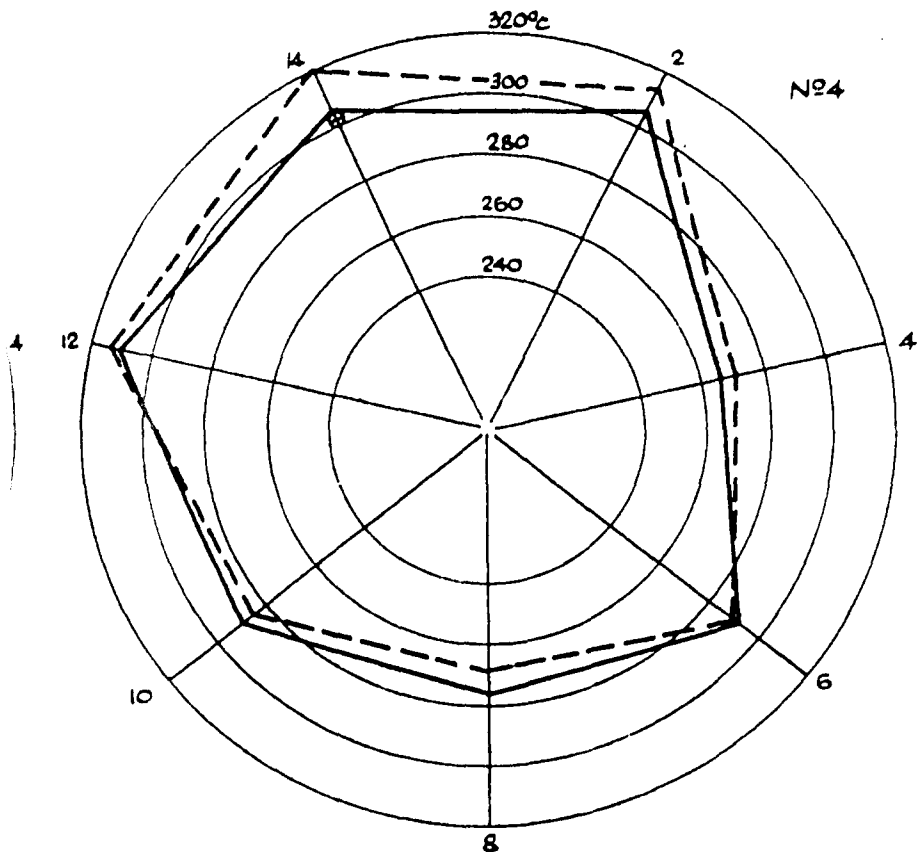
MAXIMUM CYLINDER HEAD TEMPERATURES IN CLIMB IN MGEAR AT TAKE-OFF POWER  
(CLEAN AIR, GILLS FULLY OPEN, 125 KNOTS I.A.S.) AND AT INTERMEDIATE POWER  
(RAM AIR, GILLS FULLY OPEN, 130 KNOTS I.A.S.) (I.C.A.N.)

GY-1055 PART OF REPORT NPAA.E.E/ 843/1 HASTINGS MK 2 WD476 TR 3M. CH.D.LANG APP. bud for Sof P 31.7.53



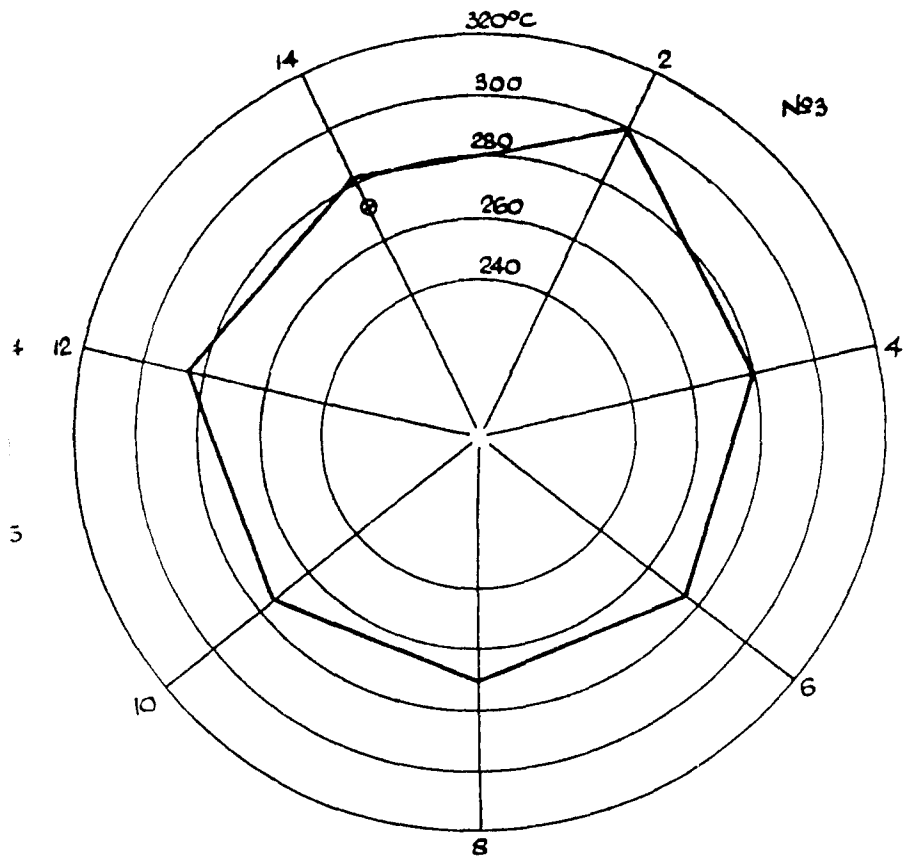
CYLINDER  
 4500FE

FIG.6.



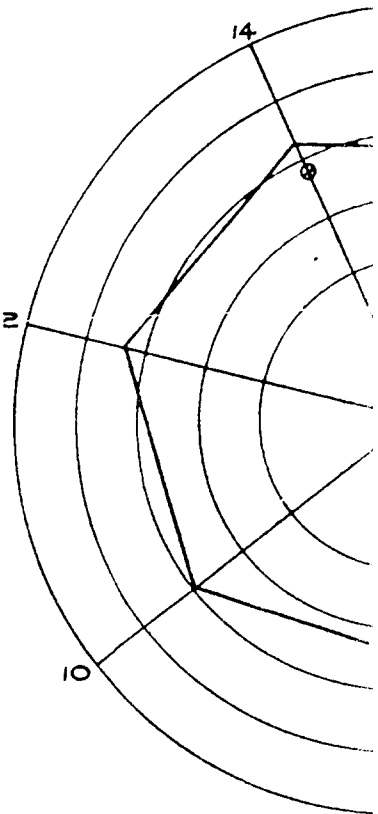
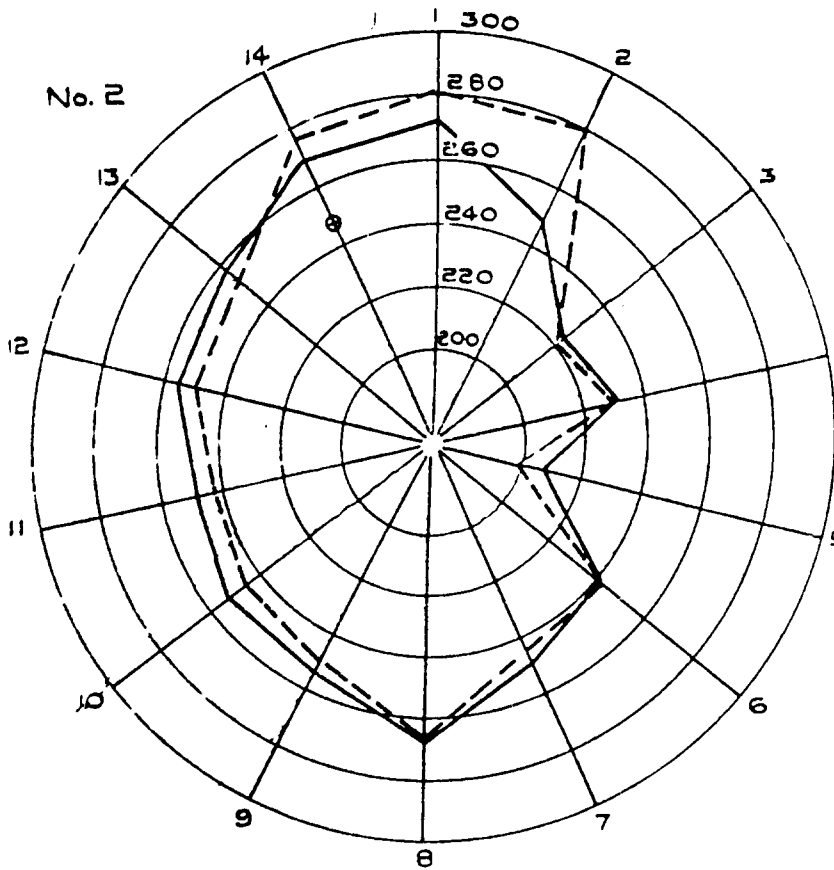
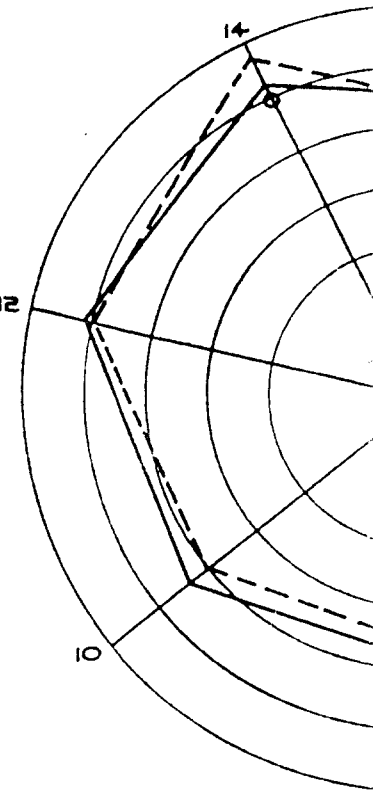
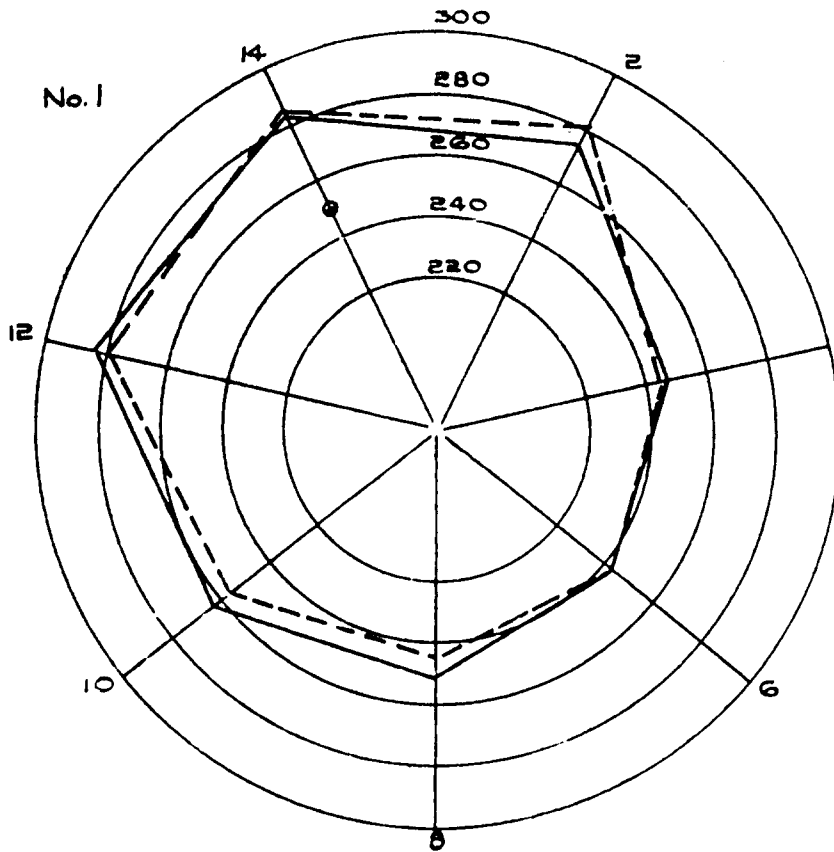
CYLINDER HEAD TEMPERATURE  
LIMITATION = 310°C

- FANS ON.
- - - - FANS OFF (1, 2 & 4 ENGINES)
- ⊗ STANDARD PYROMETER ON  
Nº 14 CYLINDERS WITH FANS OFF.  
Nº 1, 2 & 4 ENGINES.



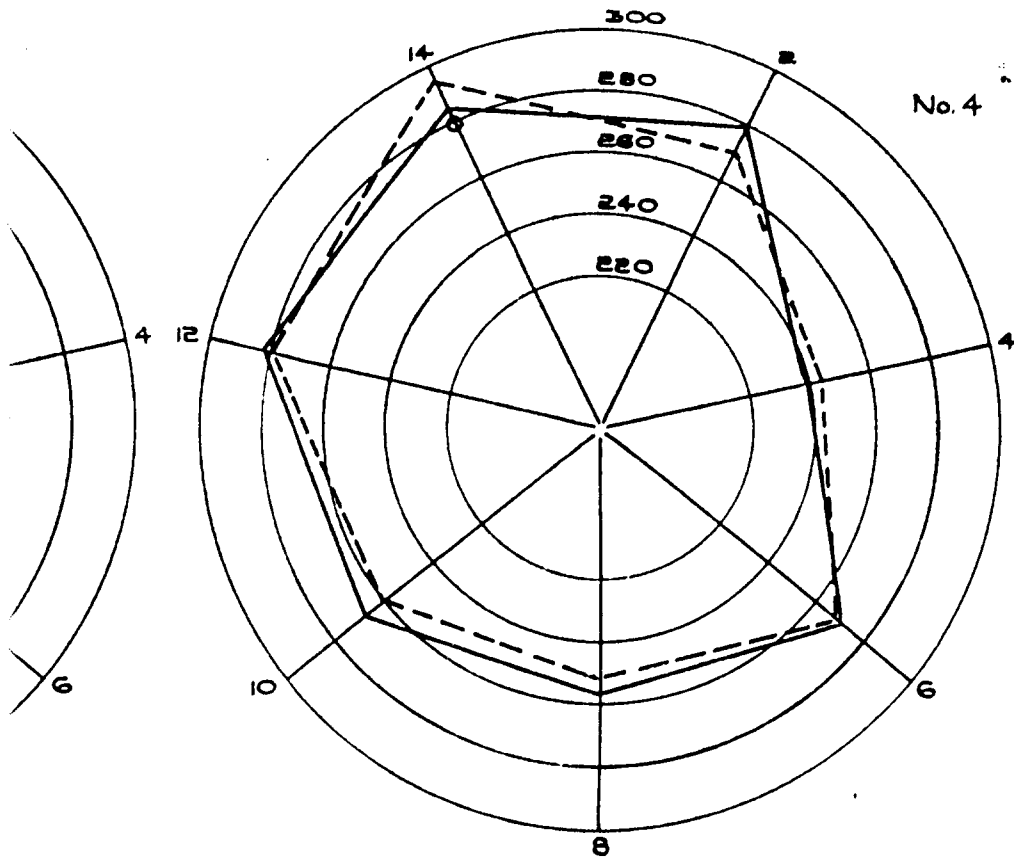
CYLINDER HEAD TEMPERATURE DISTRIBUTION IN CLIMB AT TAKE-OFF POWER;  
4500 FEET. 125 KNOTS I.A.S. CLEAN AIR. GILLS FULLY OPEN. 'M' GEAR. (I.C.A.N.)

SK N° 4-B34 19 PART OF REPORT N° 3-A-E-E/ 8-3/1 HASTINGS MK 2 WD 476 TR. 11.0' CH. D. LANG APP - blank for Sef P (31-7-53)



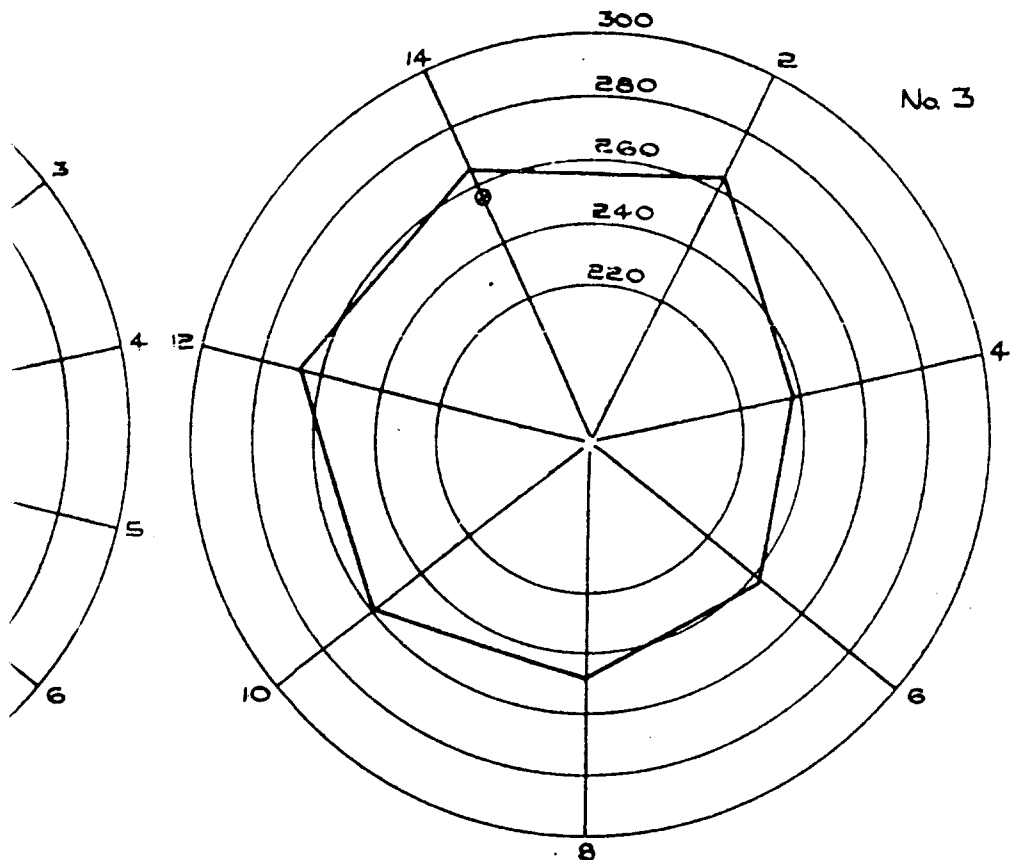
CYLINDER  
POWER 80

FIG. 7

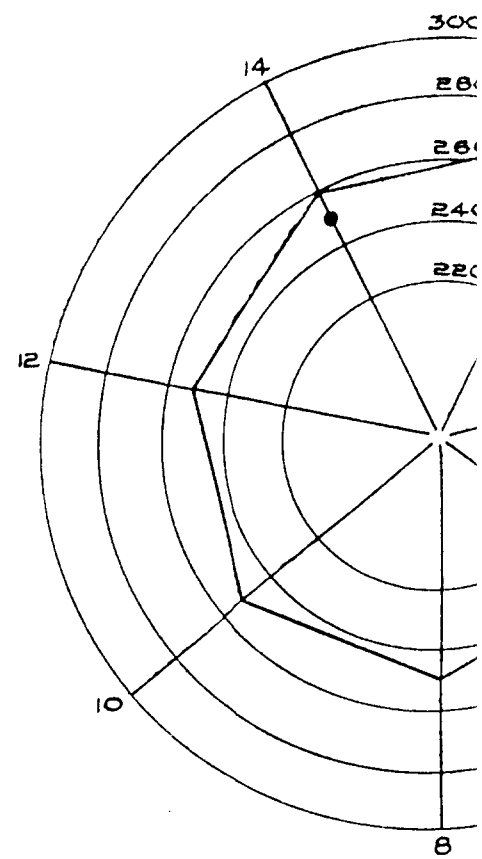
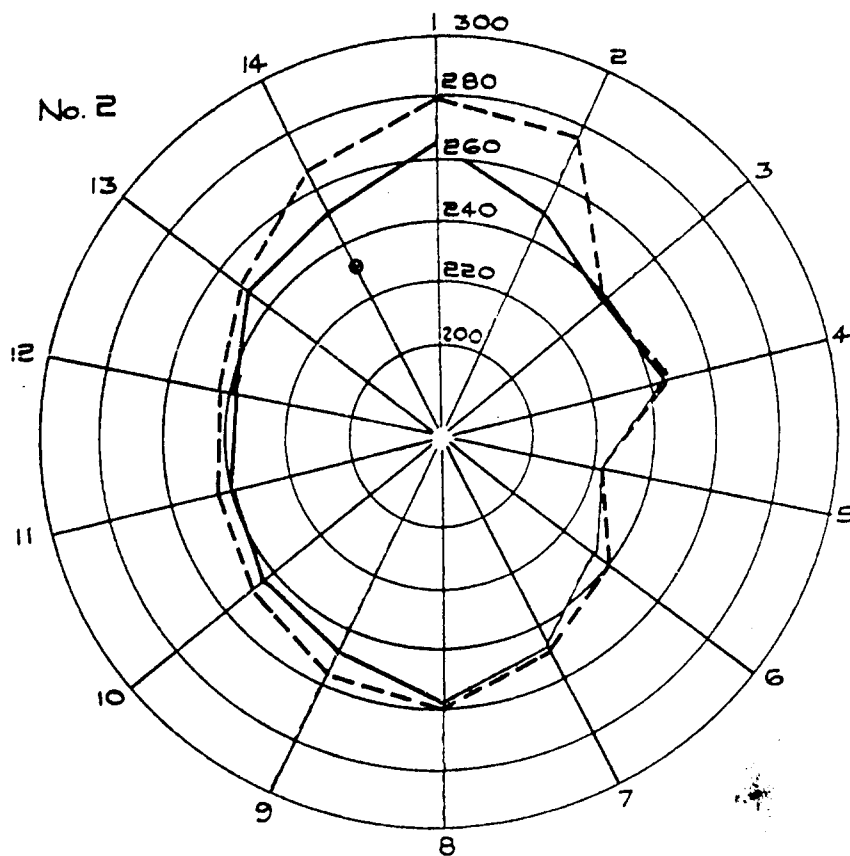
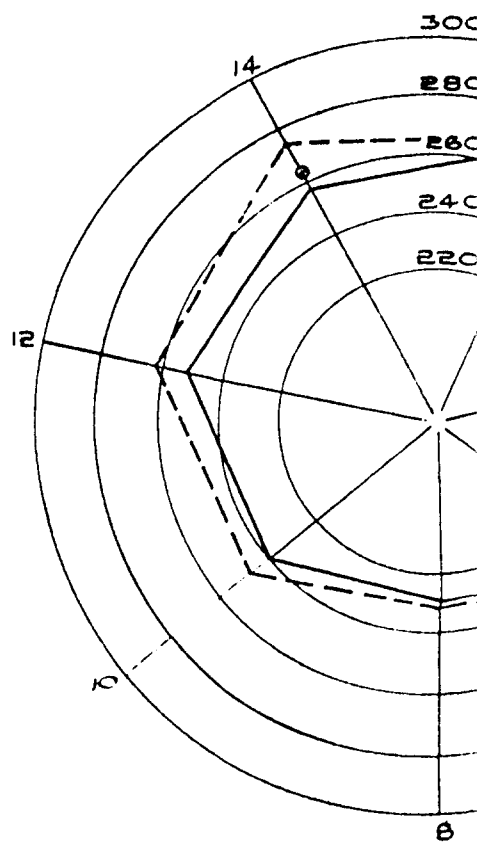
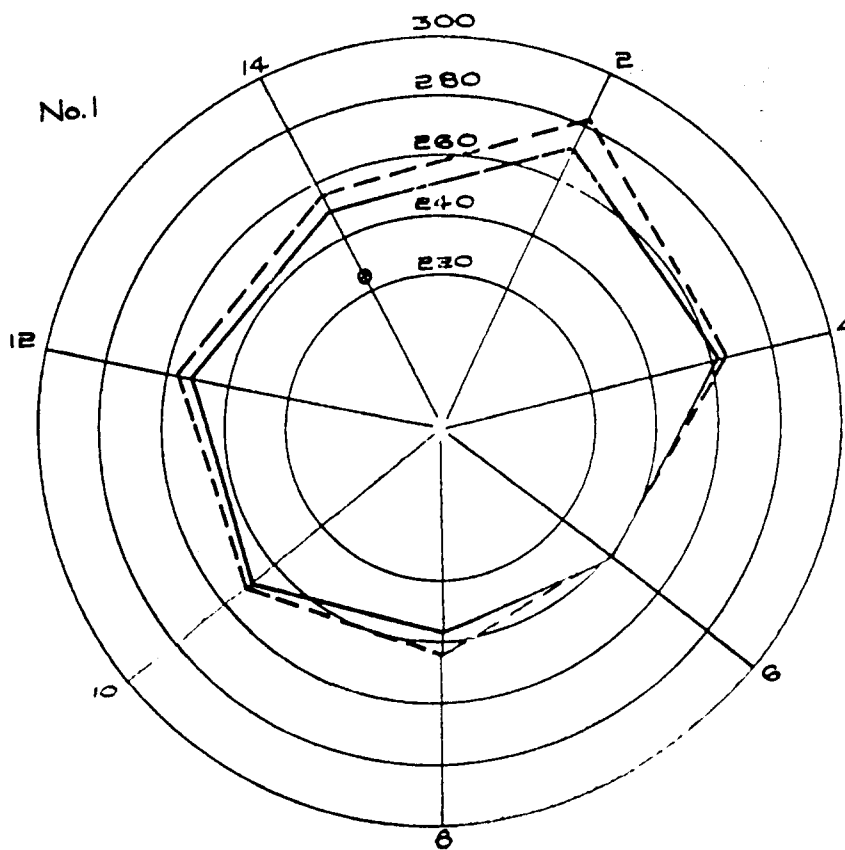


CYLINDER HEAD TEMPERATURE  
LIMITATION : 300 °C.

- FANS ON.
- FANS OFF (1, 2 & 4 ENGINES).
- STANDARD PYROMETER  
ON N° 14 CYLINDERS.  
WITH FANS OFF N°s 1, 2 & 4  
ENGINES.

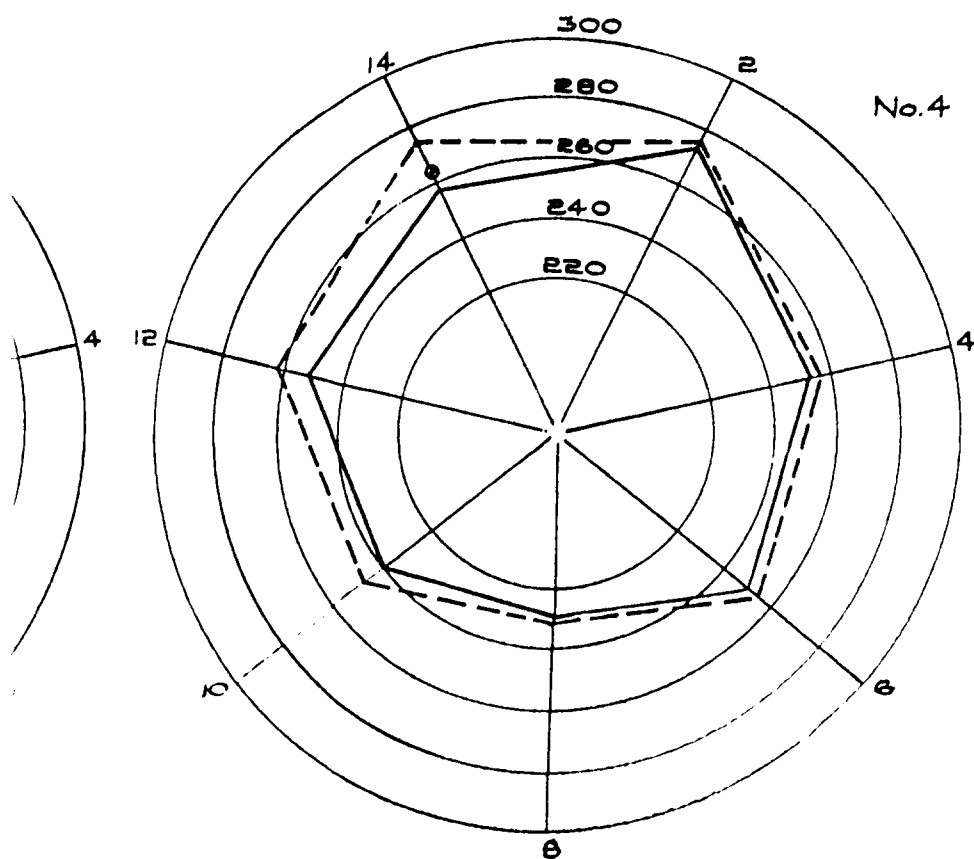


CYLINDER HEAD TEMPERATURE DISTRIBUTION IN CLIMB AT INTERMEDIATE  
POWER 8000 FT. 130 KNOTS I.A.S. RAM AIR GILLS FULLY OPEN 'M' GEAR  
(I.C.A.N.)



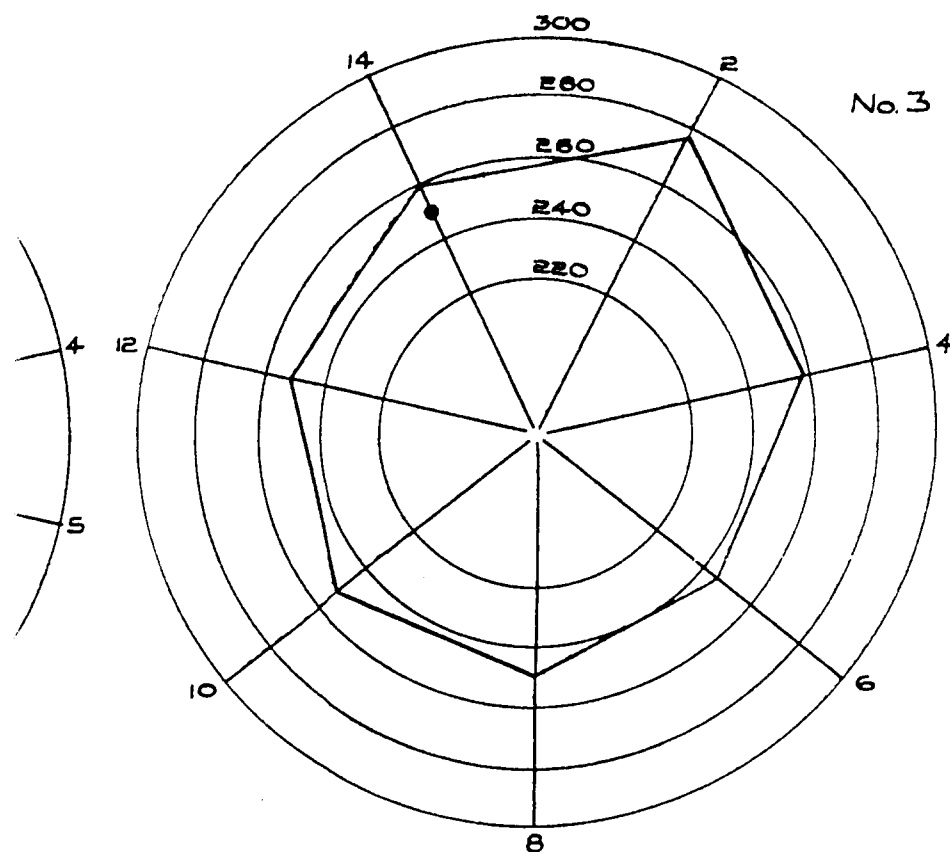
CYLINDER  
 CRUISE PO  
 GILLS SHU

FIG. 8

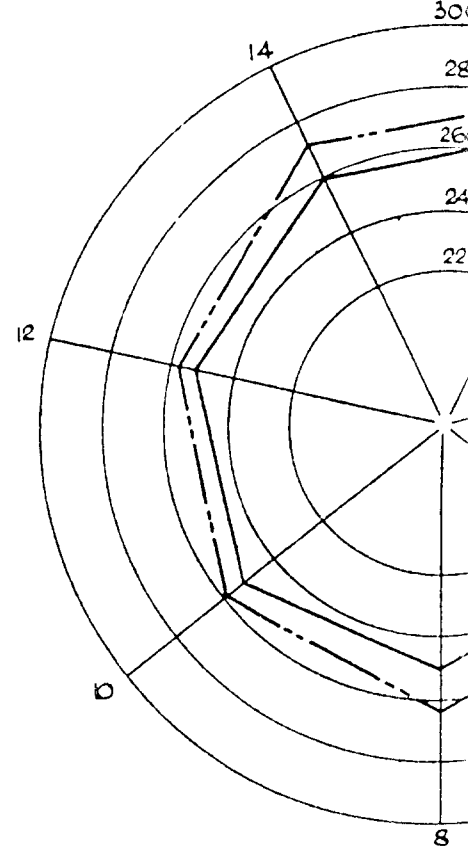
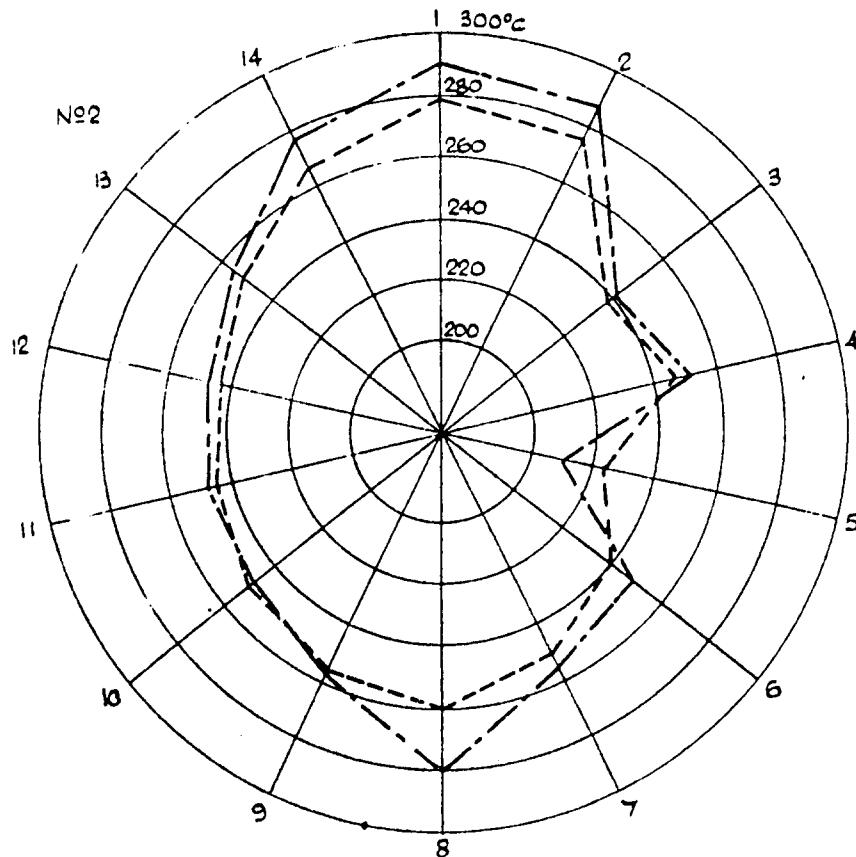
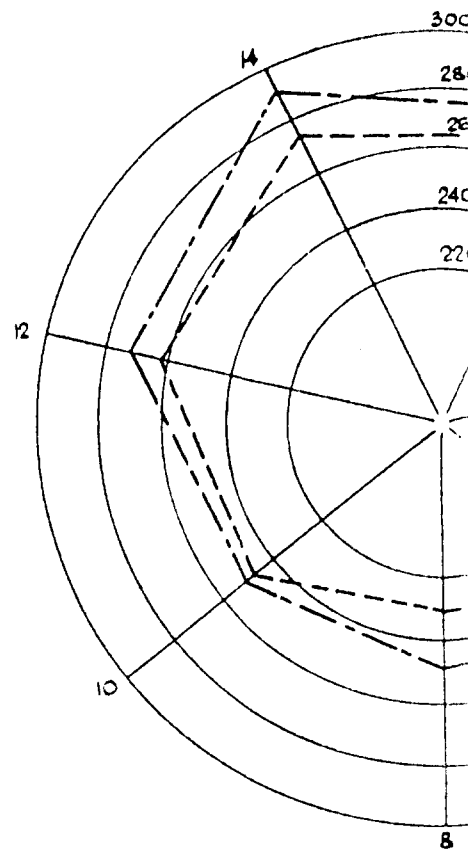
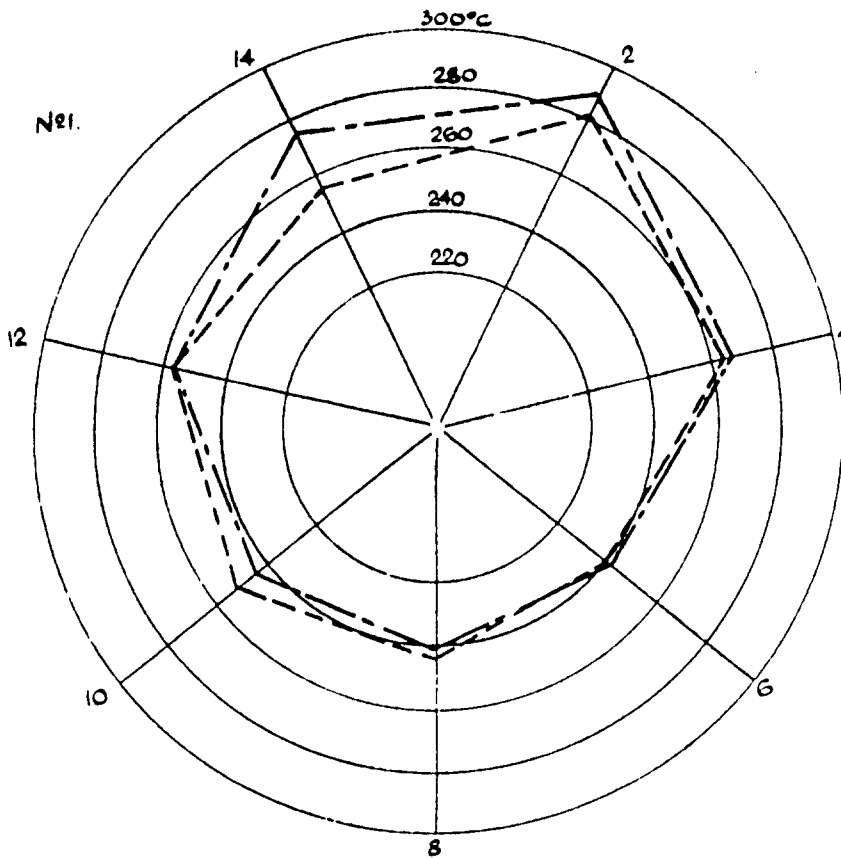


CYLINDER HEAD TEMPERATURE  
LIMITATION - 300 °C

— FANS ON  
- - FANS OFF (1, 2 & 4 ENGINES)  
● STANDARD PYROMETER ON  
N° 14 CYLINDERS, WITH FAN  
OFF N° 1, 2 & 4 ENGINES.

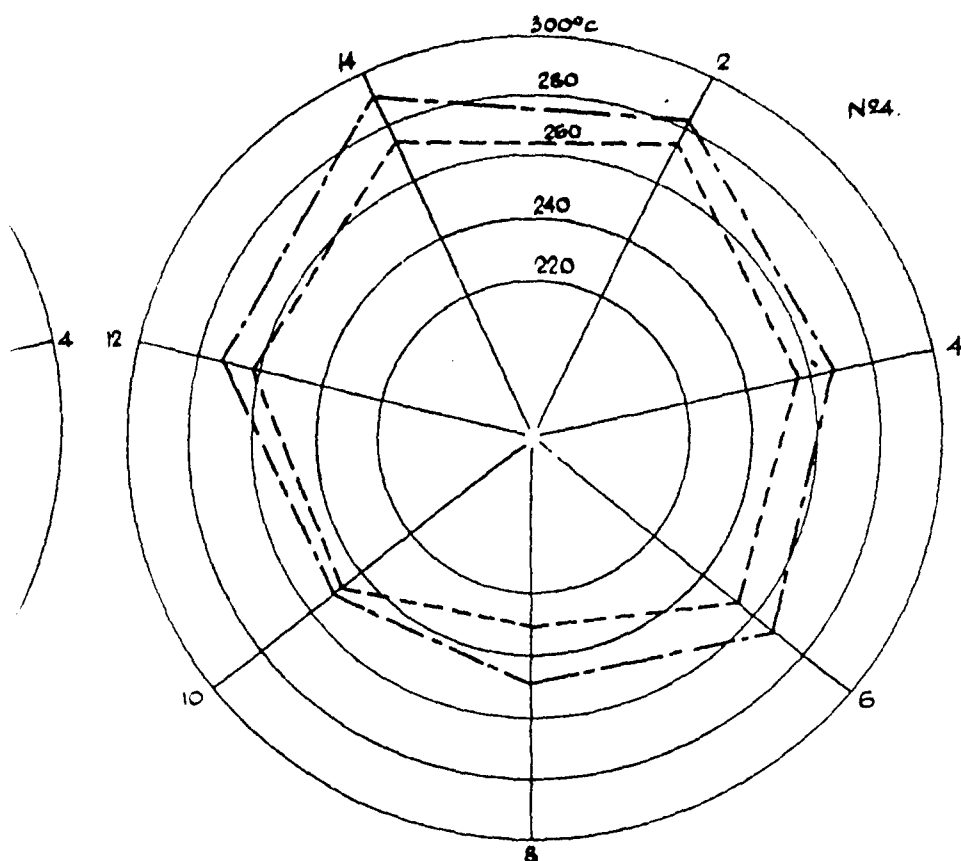


CYLINDER HEAD TEMPERATURE DISTRIBUTION IN LEVEL FLIGHT AT MAX.  
CRUISE POWER, WEAK MIXTURE. 8000 FT 193 KNOTS I.A.S. RAM AIR.  
GILLS SHUT. M GEAR. EXTERNAL STORES NOT FITTED. (I.C.A.N.)



CYLINDER  
 TUNING  
 SHOWN

FIG.9.



CYLINDER HEAD TEMPERATURE  
LIMITATION = 300°C.

FANS OFF N°3, 2 & 4 ENGINES.

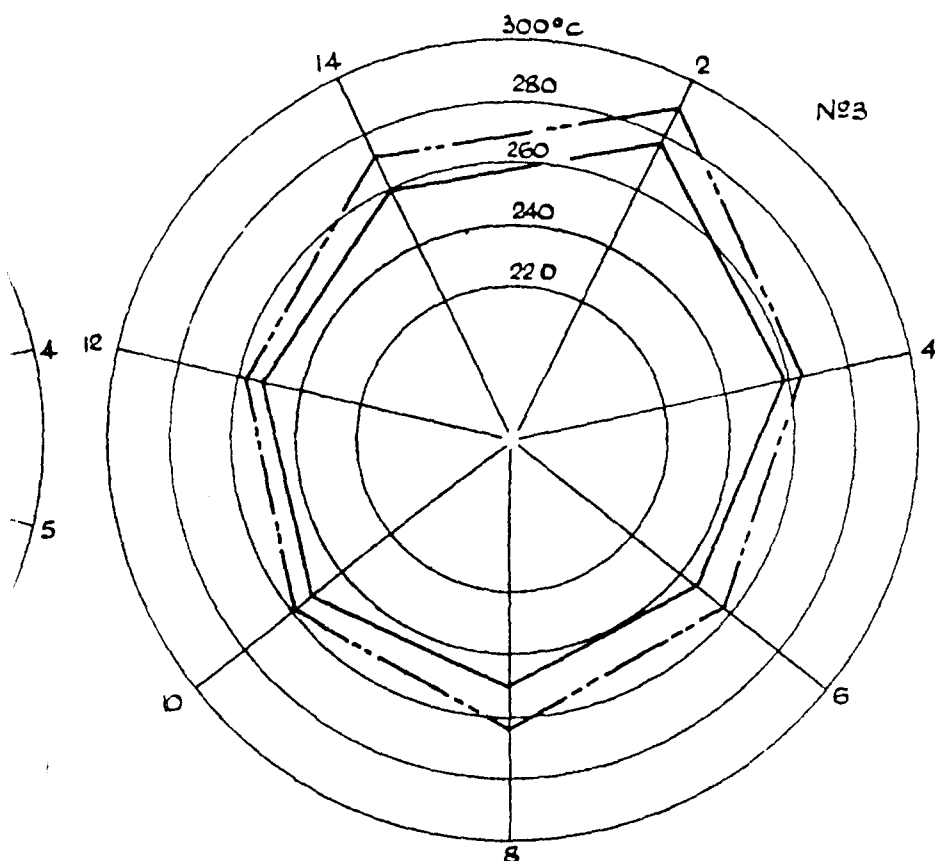
----- EXTERNAL STORES OFF  
GILLS SHUT.

----- EXTERNAL STORES ON.  
GILLS FULLY OPEN ON N°1.  
GILLS HALF OPEN ON N°3 2 & 4.

FAN ON N°3 ENGINE.

----- EXTERNAL STORES OFF.  
GILLS SHUT.

----- EXTERNAL STORES ON.  
GILLS HALF OPEN.



I.A.S. WITHOUT EXTERNAL STORES :- 193 KTS.

I.A.S. WITH EXTERNAL STORES ON :- 152 KTS.

\* EXTERNAL STORES CONSIST OF  
20 CANNISTERS.

CYLINDER HEAD TEMPERATURE DISTRIBUTION IN LEVEL FLIGHT AT MAXIMUM CON-  
TINUOUS POWER; WEAK MIXTURE. 8000 FEET. I.A.S. AS SHOWN. RAM AIR. GILLS AS  
SHOWN. 'M' GEAR. EXTERNAL STORES ON & OFF. (I.C.A.N.)

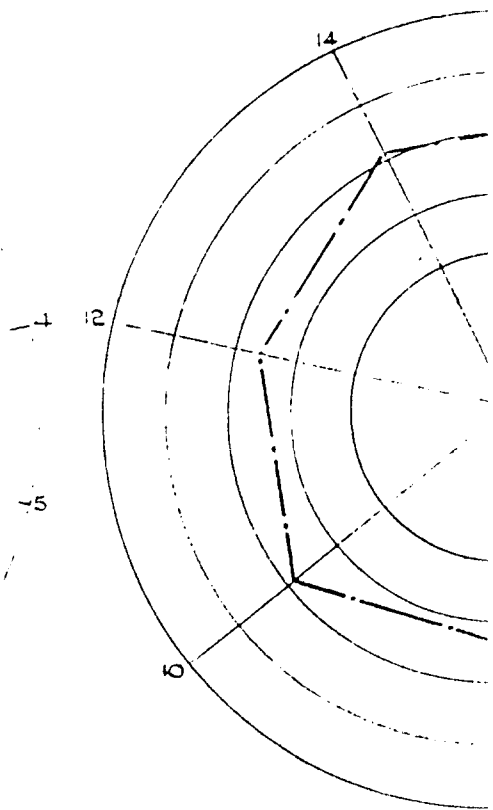
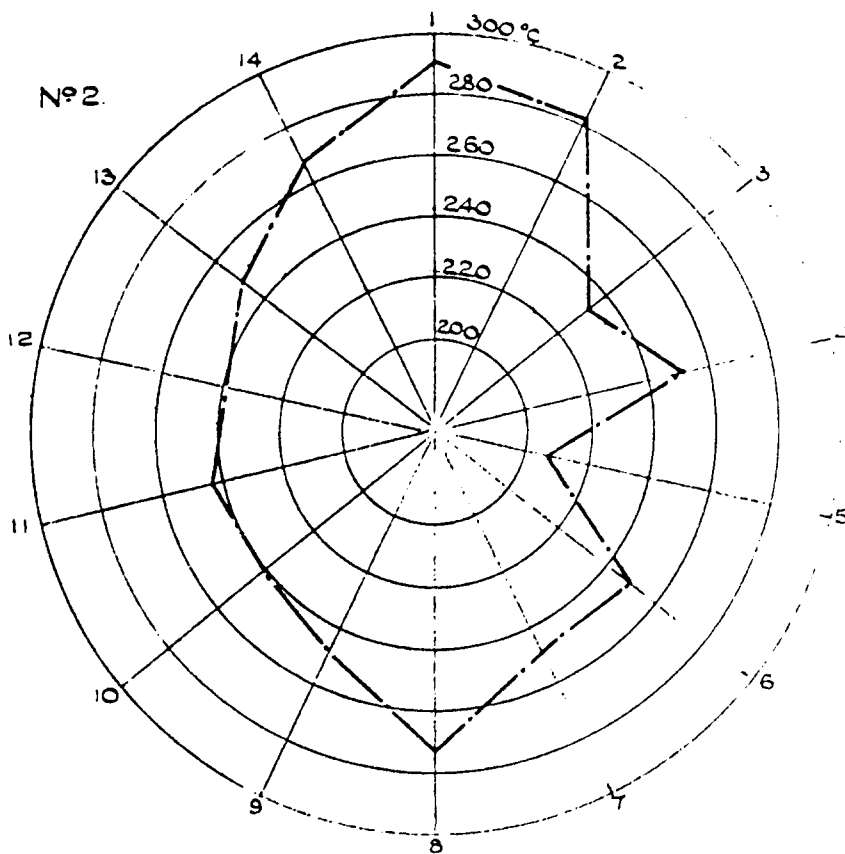
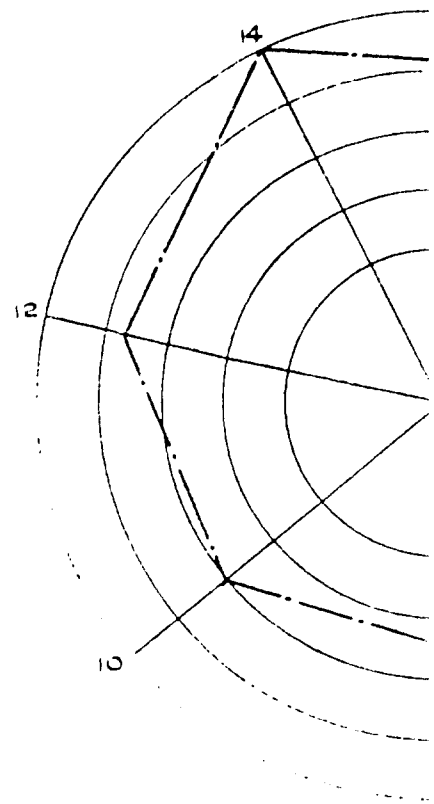
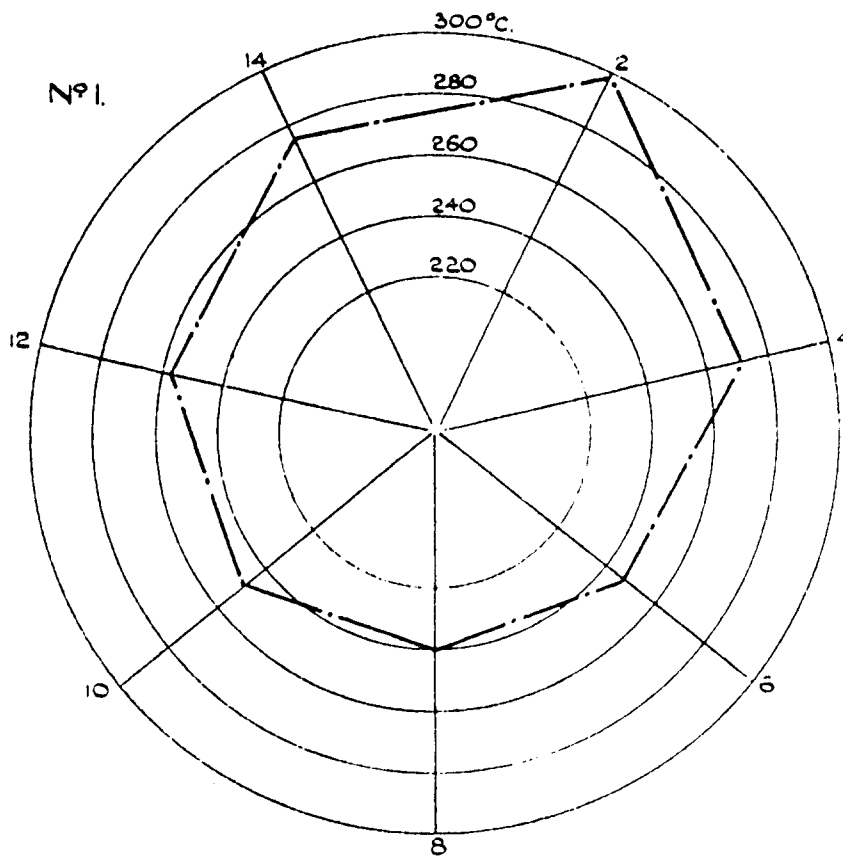
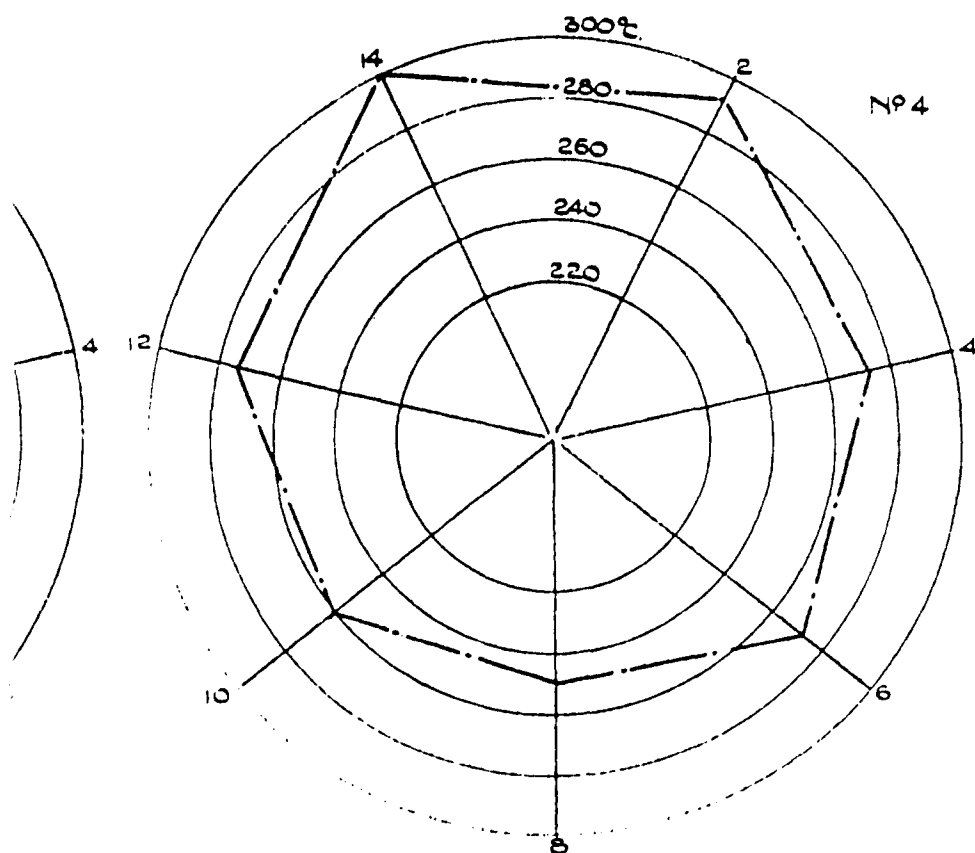


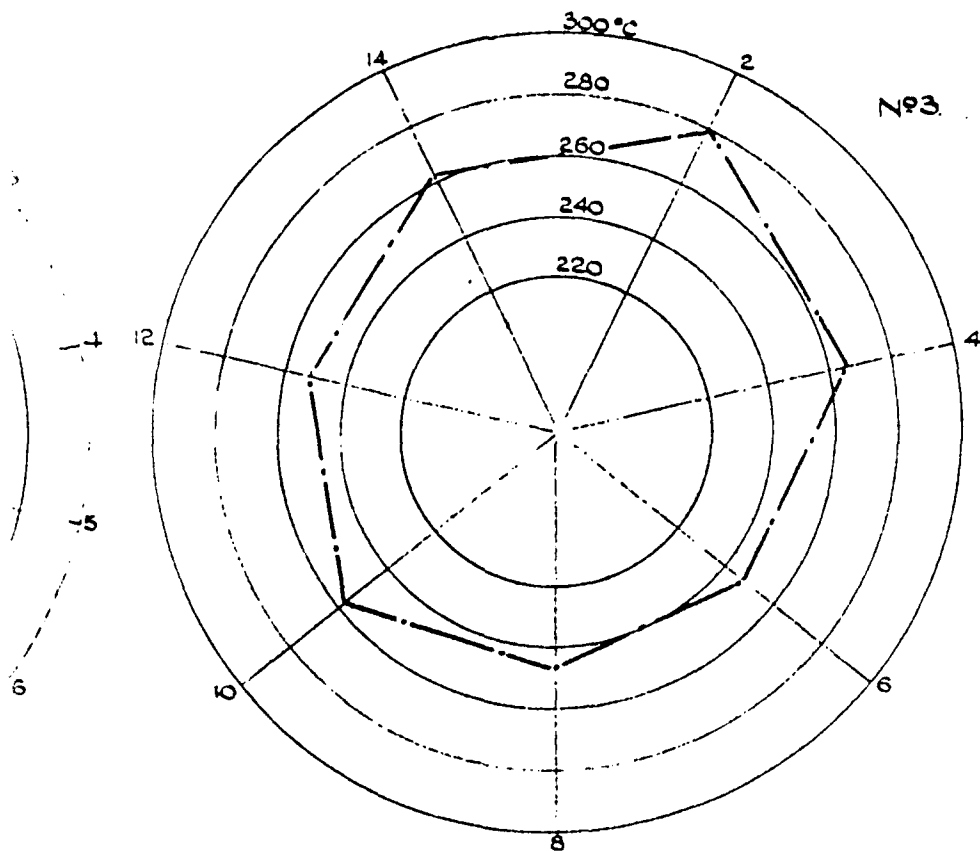
FIG.10.



CYLINDER HEAD TEMPERATURE  
LIMITATION - 300 °C

FANS OFF N°1,2 & 4 ENGINES.  
FAN ON N°3 ENGINE.

GILLS HALF OPEN ON N°1 & 2 ENGINES.  
GILLS SHUT ON N°3 & 4 ENGINES.



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Title: Hastings Mk2 (4 Hercules 106): engine cooling tests at 80,000lb with and without cooling fans and external stores

Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years

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